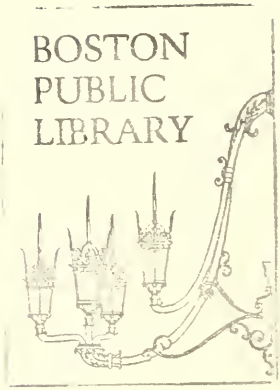
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Vol. XLIII. JUNE, 1900.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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No. 870.

THE SOUTH TERMINAL STATION, BOSTON, MASS.

By GEORGE B. FRANCIS, M. Am. Soc. C. E.

PRESENTED AT THE ANNUAL MEETING, JANUARY 18TH, 1900.

WITH DISCUSSION.

INTRODUCTION.

The construction of the Southern Terminal Station in Boston by The Boston Terminal Company has reduced the number of terminal stations in that city to two: One, the Northern Station, serving the railroad lines entering Boston from the Northeast, North and Northwest, and taking the place of terminal stations formerly used by the Boston and Maine, Boston and Lowell, Fitchburg and Eastern Railroads; the other, the Southern Station, serving the railroad lines entering Boston from the West, Southwest and South, and taking the place of terminal stations formerly used by the Boston and Albany, Old Colony, Boston and Providence and New England Railroads; all the roads entering the Southern Station, except the Boston and Albany, being leased to the New York, New Haven and Hartford Railroad Company.

This latter station has just been completed, and its engineering features are described and illustrated in this paper. The project for

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Station
4.S

this station was conceived early in the year 1896; the charter was approved June 9th, 1896; and The Boston Terminal Company, consisting of the five railroad companies, as follows: The Boston and Albany Railroad Company, The New England Railroad Company, Boston and Providence Railroad Corporation, Old Colony Railroad Company, and The New York, New Haven and Hartford Railroad Company, each taking $100 000 of stock (all other funds being raised by terminal bonds), was immediately organized.

Surveys and plans were started July 1st, 1896; general plans were approved by the Mayor and Railroad Commissioners on December 22d, 1896, and January 4th, 1897, respectively; construction was begun in a preliminary way in January, 1897, and comprehensively in April, 1897.

The Old Colony and New England Railroads were transferred to the station January 1st, 1899; the Boston and Albany Railroad July 23d, 1899, and the Boston and Providence Railroad September 10th, 1899.

With a few minor exceptions the work at this date (September, 1899) is entirely completed. The site selected embraces the location of the old New England terminal at the foot of Summer Street, a part of the Old Colony terminal on Kneeland Street, as well as all the land lying between these stations and alongside of the latter, bordering upon the Fort Point Channel, a part of Boston Harbor. A portion of Federal Street, Mount Washington Avenue, and several minor streets have been abandoned, and Summer and Cove Streets and Dorchester Avenue have been extended and widened to serve public street traffic in their stead.

Aside from the terminal work undertaken by The Boston Terminal Company, first it has been necessary for the City of Boston to construct the new streets; land for the same, equivalent to that taken from streets, being given to the city by the Terminal Company, and to relay the public sewers and water pipes in the vicinity. This street work includes a sea wall along the Fort Point Channel about 2 000 ft. in length to sustain Dorchester Avenue; a new street and drawbridge 100 ft. wide for Summer Street extension; also, some bridge work in connection with Broadway and Albany Street. Since the plans for the station were approved by the Mayor and Railroad Commissioners, an additional street and bridge over the terminal grounds and Fort Point Channel, making an extension of Cove Street to Dorchester

MAP OF THE
BUSINESS PORTION
OF THE
CITY OF BOSTON
1896

PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XLIII, No. 870.
FRANCIS ON BOSTON SOUTH TERMINAL.

MAP OF THE
BUSINESS PORTION
OF THE
CITY OF BOSTON.
1899
SCALE OF FEET
0 200 400 600

Avenue, has been proposed by the city, but the construction of the same has not yet been undertaken, and this street is therefore shown in dotted lines on the general plan, Plate VI.

Second, it has been necessary for the Old Colony, New England and Boston and Providence Railroads, through their lessor, the New York, New Haven and Hartford Railroad Company, to connect with the terminal location the first two by means of a new six-track rolling-lift drawbridge over Fort Point Channel, and the third by constructing a very difficult and expensive stretch of four-track road-bed about a mile long, from Dartmouth Street, on the Back Bay, so-called, to the terminal, alongside of the road-bed of the Boston and Albany Railroad, in the heart of Boston.

It is not intended in this paper to describe further the work done by the City of Boston or the work done on the connections by the New York, New Haven and Hartford Railroad Company, but rather to describe the work of The Boston Terminal Company exclusively.

The land taken (land, exclusive of streets), was owned by fifty-six private parties, three railroad companies and the Commonwealth of Massachusetts. A complete survey was made of the entire tract, and of each individual piece of land. These surveys have been filed in plat-book form for permanent record. Location maps and descriptions were also made for the public records, as required by the charter. The value of the lands thus taken for the terminal aggregated in the neighborhood of $9 000 000. It was necessary to make thorough search of land records in order to interpret the survey, as there were some joint dockage rights and wharfage grants which could not be otherwise understood.

Borings.

Borings were made at various points all over the site, and the results are faithfully set forth on the cross and longitudinal sections of the station. Generally, the site is underlaid with clay, mixed with some sand and gravel, and pile foundations were decided upon, the piles to be held firmly by friction.

Pile Test.

In order to get an idea as to the supporting power of piles in this clay, three ordinary spruce piles were driven, and loaded with 60 tons of pig-iron, with no resulting settlement. A description of this is

given with Fig. 1, Plate XII, more in detail. The value of such an isolated test is questionable, as the results might be totally different a short distance away. In this instance, however, the strata being quite uniform, the results were considered fairly indicative of what might be expected generally at this site.

Originally, the entire area was flooded by the tide at high water, and several series of wharves had been built, some of stone work, and some of timber cribs of all sorts and construction.

Encumbrances.

At the time of starting the work public travel existed over streets to be abandoned; sewers were in use upon which it was necessary to expend upwards of $100 000 to readjust them to the new conditions; water pipes and hydrants were in service; and telegraph, telephone, electric light, police and fire-alarm wires were in the way. Electric conduits and gas mains also encumbered the ground.

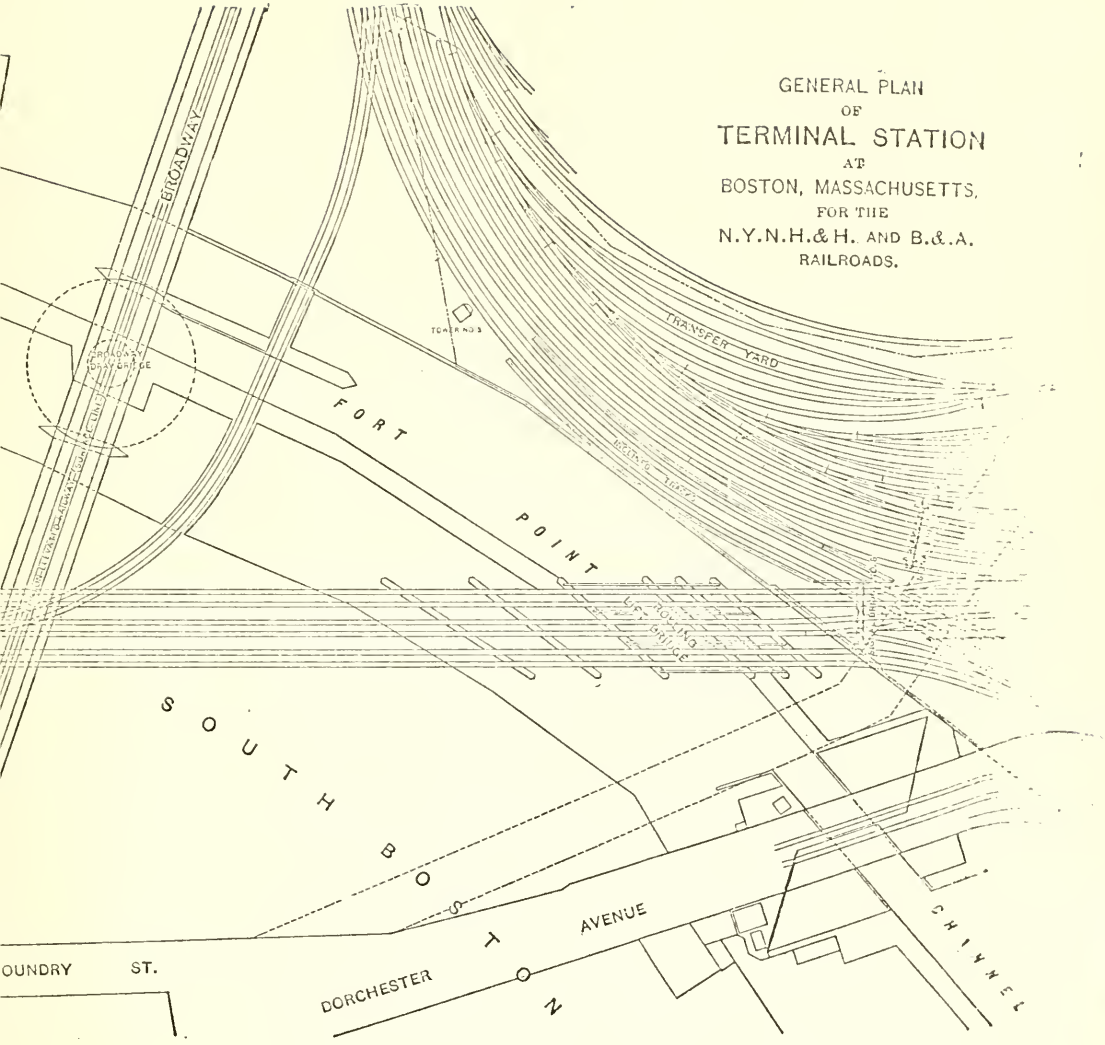
There were many leases of property not yet expired, even after the extinguishment of the owners' titles. All the coal in the great coal pockets, some of which were in the act of loading up from vessels, as well as all the stock and machinery in the various buildings, had to be removed before the buildings themselves could be torn down. About 210 buildings were removed, a few of them substantial modern structures, but mostly old dwellings, storage warehouses, freight houses, coal pockets, etc. There were a few manufacturing buildings and two very large gasometers.

General Plan.

While the above work was going on, many plans were made for the general layout of the entire station, finally resulting in the double-floor arrangement which has been constructed, the upper floor to be used for regular steam railroad trains, and the lower floor for suburban trains, using a special motive power, and running upon the same main road-bed.

As the railroad traffic about Boston has some characteristics different from almost any other American city, a short account of the line of reasoning which led up to this form of station will not be out of place.

Upon the railroad routes within 50 miles of Boston, about 50 000 000


GENERAL PLAN
OF
TERMINAL STATION
AT
BOSTON, MASSACHUSETTS,
FOR THE
N.Y.N.H.& H. AND B.&.A.
RAILROADS.
BROADWAY
TOWER NO 3
TRANSFER YARD
FORT
POINT
CHANNEL
SOUTH
BOSTON
AVENUE
DORCHESTER
OUNDRY ST.
CHANNEL

GENERAL PLAN
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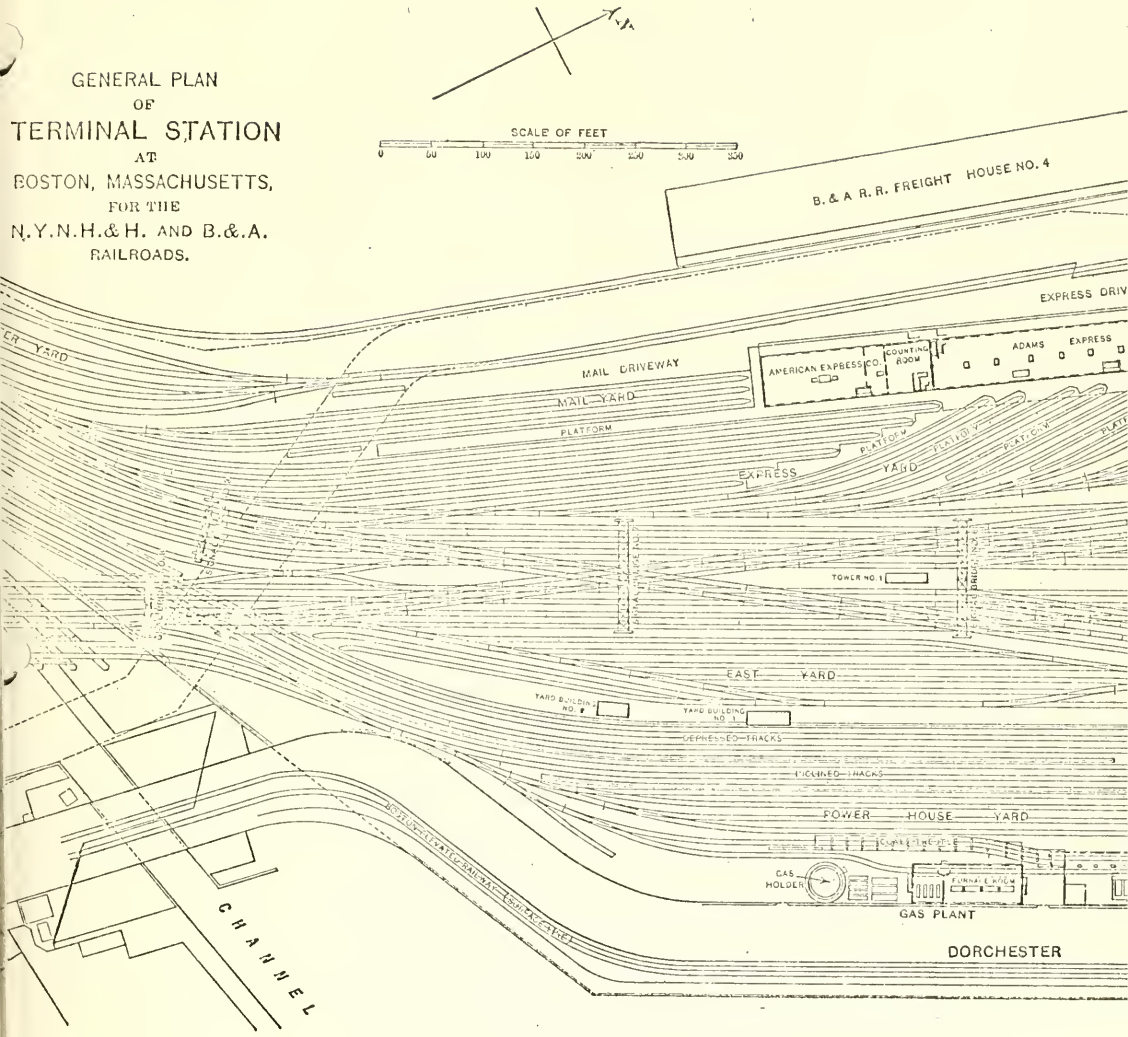
TERMINAL STATION
AT
BOSTON, MASSACHUSETTS,
FOR THE
N.Y.N.H.&H. AND B.&A.
RAILROADS.



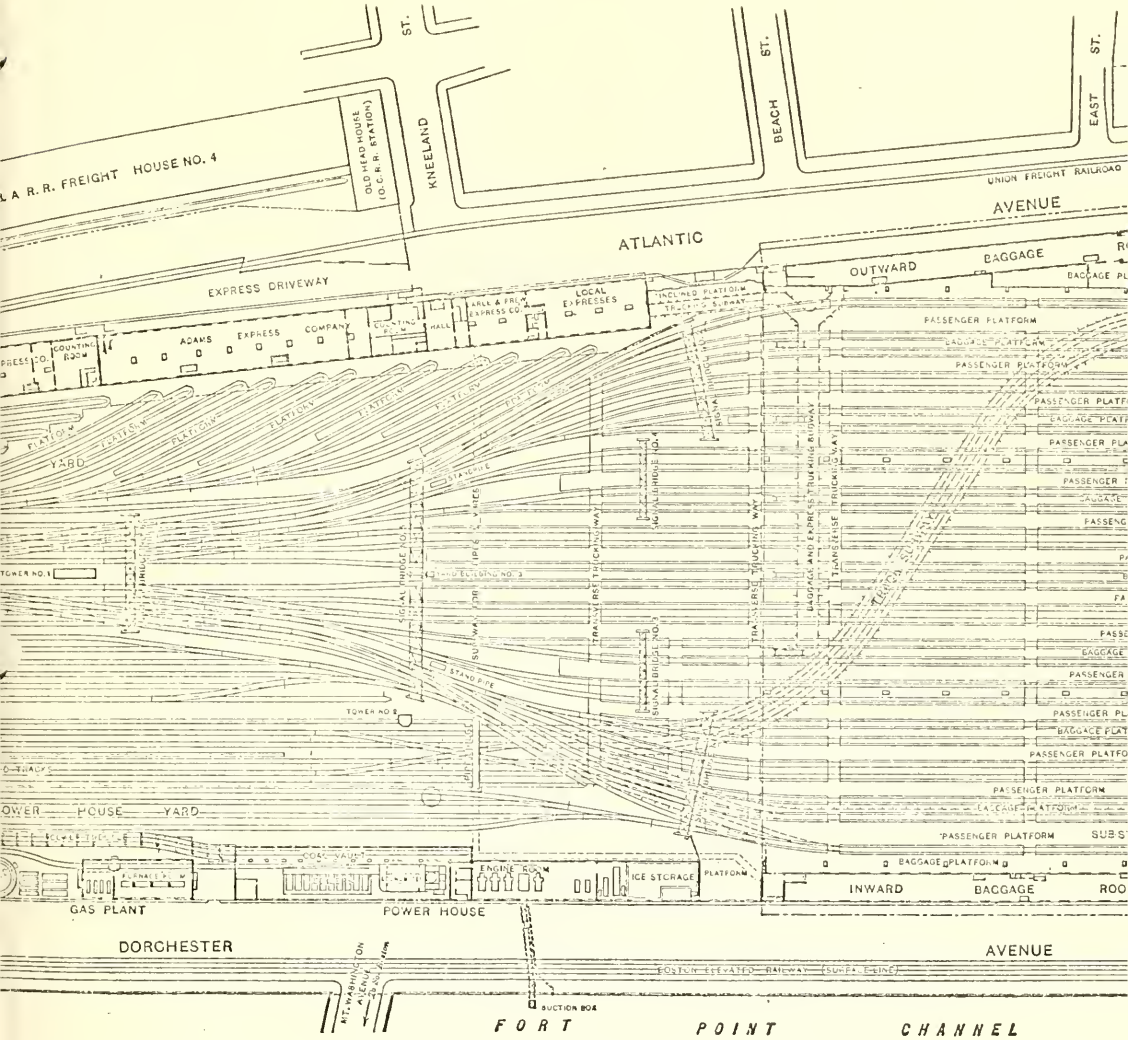
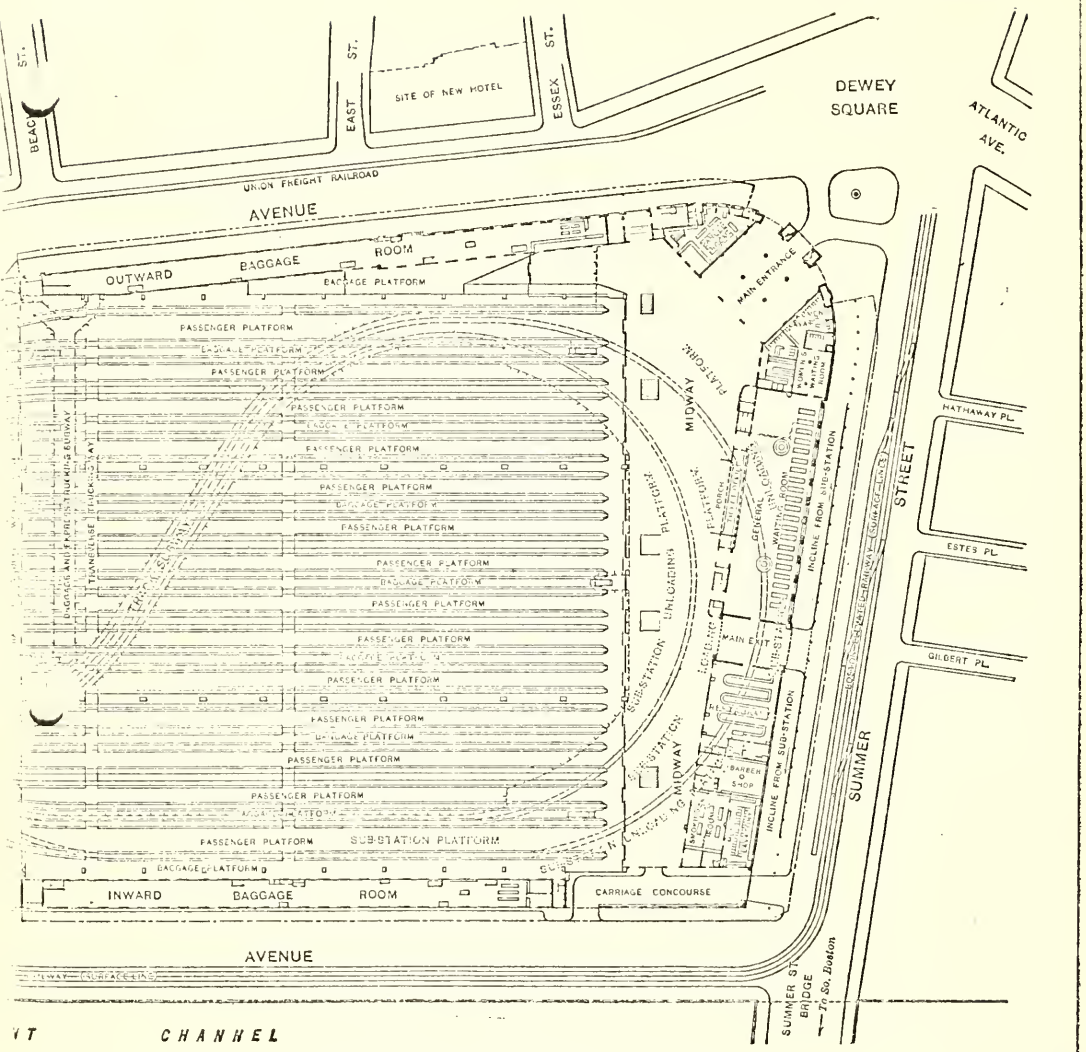

L A R.R. FREIGHT HOUSE NO. 4
OLD HEAD HOUSE (O. C. R. R. STATION)
KNEELAND ST.
BEACH ST.
EAST ST.
UNION FREIGHT RAILROAD
ATLANTIC AVENUE
EXPRESS DRIVEWAY
ADAMS EXPRESS COMPANY
COUNTING ROOM
ARLL & FREE EXPRESS CO.
LOCAL EXPRESSES
OUTWARD BAGGAGE
PASSENGER PLATFORM
BAGGAGE PLATFORM
YARD
TOWER NO. 1
TOWER NO. 2
TOWER NO. 3
TOWER NO. 8
TRANSFER BRIDGE NO. 4
TRANSFER BRIDGE NO. 5
TRANSFER TRUCKING WAY
STAND PIPE
POWER HOUSE YARD
COAL YARD
ENGINE ROOM
ICE STORAGE
PLATFORM
INWARD BAGGAGE
GAS PLANT
POWER HOUSE
DORCHESTER AVENUE
BOSTON ELEVATED RAILWAY (SUMMER LINE)
SUCTION BOX
FORT POINT CHANNEL

PLATE VI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XLIII, No. 870.
FRANCIS ON BOSTON SOUTH TERMINAL.



passengers are carried to and from the city each year, nearly equally divided between the North and South Stations.

The close approximate population within the 50-mile, or say, suburban, limit is 2 392 000. Within the same limit around Philadelphia it is 2 289 000; around Chicago, 1 188 000; around St. Louis, 874 000; and around New York, 4 754 000; New York, only, exceeding Boston. These figures show the reason for large terminal facilities in Boston, and the existence of the South Terminal Station.

It was decided at an early date that the new station must be so built that the new motive powers, electricity and compressed air, one or both, could be used therein; that a large increase in suburban trains, due to smaller train units and more frequent service, could be had, and that every effort possible should be made to remove the handling of baggage from the passenger platforms.

The first plans contemplated only a single floor for train service, but after arranging as well as possible for the various controlling features, making numerous studies for the exclusion of baggage trucks from the passenger platforms, and developing several ways of expeditiously handling electric cars, considering both high platforms on a level with the floor of such cars, and low platforms as an alternative, it was found that such unusual features tended to use up space, and that instead of 30 or more tracks, which it was hoped could be had, the number was reduced to 28. This was discouraging, as the old stations contained an aggregate of 25 tracks, and the increase of only 3 did not promise that opportunity for future growth which it was reasonable to expect.

There being no reasonable hope that a greater width of land could be secured, attention was directed to the possibility of divorcing the suburban, or short-distance, service, from the long-distance service, and placing the former at a different level, thus doubling the room for tracks on certain areas. The first sketch of this sort diverted the proposed suburban tracks about half a mile from the station, and by a gradually rising grade brought several tracks on either side of the train shed to a level about 24 ft. above the main floor. These were to be stub tracks, like those on the main floor.

This arrangement did not do away with the necessary switch system for making up trains outside of the station for each floor level; and upon its development, it was seen that if the elevated stub tracks could

be connected in the form of loops, the train movements would be very much lessened, and the number of switches at the entrance largely reduced. The extreme width of the station made the loop connection possible, and a plan was drawn accordingly. This was the first loop-track study. There was some doubt, however, as to the advisability of having upper platforms about 28 ft. above the main floor (which would be the case if high platforms were used) on account of the appearance of the structure, the difficulty of handling baggage, the nuisance from the smoke and steam of the locomotives below, as well as the advisability of avoiding stairs. The approaching grades were also steeper than was desirable.

The possibility of a suburban loop-track service upon a floor beneath the main floor was considered next. As the main floor of the station was designed at that time to be only about 6 ft. above the highest tides, it required to be raised to the highest level possible without the use of stairs at the entrances from the streets, which was prohibited. The main floor was raised 4 ft., and inclines were introduced at the entrances.

Even this placed the lower tracks, which were finally designed to be 17 ft. below the main-floor tracks, 7 ft. below very high tides. This immediately introduced the study of waterproofing this great area to shut out the water. Due consideration showed it feasible to do this without prohibitory cost. Placing the loop-tracks 17 ft. below the main floor and using high platforms for this kind of service made easier approach grades, stairways of 13 ft. rise instead of 28 ft., as was the case with elevated suburban tracks, simplified the handling of baggage, improved the appearance of the main floor, and did away with the smoke nuisance.

The main station building was also drawn, set back from Summer Street; so that inclined approaches could be had to or from the first loop-track, as well as to the main floor. Stairways were drawn from the main floor to the lower floor, so that all persons taking loop-trains at the station could reach them by going downstairs only.

Before the loop plan was adopted it was drawn in various ways and positions, sometimes with two loops, sometimes with four, sometimes with curved corners and some straight tracks; also tracks curved throughout. Studies were made of methods of handling the passengers and building the cars.

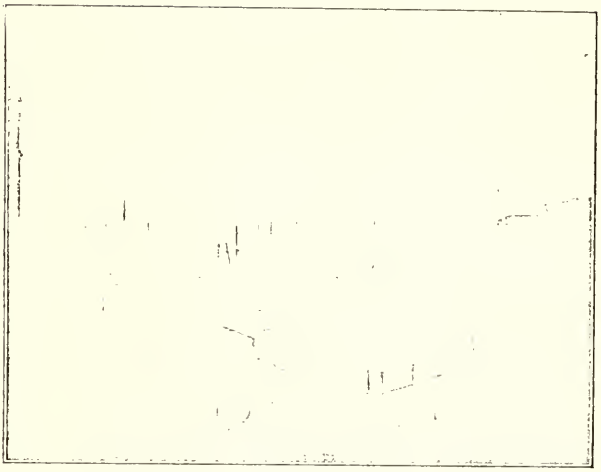


FIG. 1.—GENERAL VIEW OF WORK, JUNE 15TH, 1897.

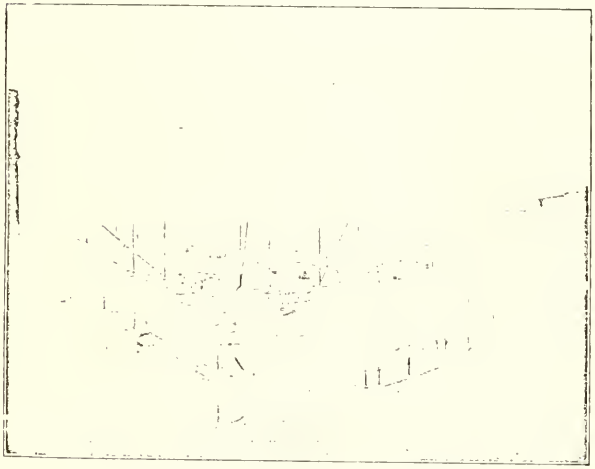


FIG. 2.—GENERAL VIEW OF WORK, AUGUST 18TH, 1897.

The one great feature which made the loop system attractive was the making of this great terminal a through station for one kind of service and a terminal station for the other. Suburban trains do not carry mails, express matter, or baggage in any quantity. They carry people only, and should be run frequently and got out of the way rapidly. The through-station idea made it possible to handle as many trains at the terminal as it is possible to run over a main line, the trains leaving their passengers and moving on without switching. If the coming motive power should be electricity, through a third rail, it will not conflict with the immense switching system which must be maintained at so large a terminal.

As this station must eventually provide for suburban trains from the four main lines, such trains must leave the station at shorter intervals than trains could be run on either main line alone. This was provided for by arranging, with a minimum amount of switches, two loop tracks to be used alternately, each capable of holding several trains, one track to be filled while the other is being cleared. By this means trains can remain in the suburban station much longer than actual time interval between trains. These loops could have been changed to operate with even a less number of switches than designed, but it would have obliged all trains from some routes to use one loop exclusively, whereas it was desirable to make the forward loop available for all routes to its full capacity.

Taking up the various engineering features connected with the problem, a description will be given of each of the more prominent ones in about the order in which they confronted the engineer.

Coffer Dam.

The coffer dam which it was necessary to construct, and without which it would have been impossible to execute the work, merits a brief description.

As the borings show an underlying stratum of clay within the reach of a single length of timber, it was evident that a continuous timber wall driven into this clay close enough to prevent leakage in the joints would positively exclude the water. With this sort of a wall surrounding the work no trouble would result in execution. In some places this line of timber wall, consisting of 6-in. splined hard pine planks, in about 40-ft. lengths, was doubled to give sufficient lateral

strength to resist pressure from open water; at other places it was a single line.

Wherever this sheet piling was driven it was necessary, first, to remove entirely any stone or timber in the way. Any failure to do this was disastrous. There were some exasperating delays in the removal of the obstructions, obliging the use of several divers and a wrecking outfit, but eventually the entire terminal excavation was shut off from the salt water on three sides, and in some pockets on four sides, with this timber wall.

From the very start up to the present date there has been no flooding of the lower floor, the coffer dam having effectually done its work. The cost of this dam has been about $75 000. It is also of use in connection with the permanent shutting out of high tides, thus reducing excessive pressure on the waterproofing. By some it has been considered that the coffer dam presented the most difficult feature of the undertaking, and that without success in this particular, it would have been impossible to execute the work. The total length of this dam was about 3 000 ft.

Waterproofing.

The permanent waterproofing sheet, which underlies the whole lower floor, consists of ten layers of tarred paper, swabbed together with hot coal-tar pitch. The layers are carefully lapped, and all built in place. This continuous sheet of waterproofing, amounting to 56 000 sq. yds., or upwards of 10 acres, is laid, where horizontal, upon a concrete base, troweled to a smooth surface. In some of the softer places boards were laid down under the concrete base, but usually this base, 6 ins. thick, rests upon the ground. Where the waterproofing is on the vertical walls, it is backed up with 8 ins. of brick work. In all cases the horizontal sheet lies between the pile heads and the granite masonry above.

Upon the waterproofing sheet, where it is not weighted down with walls, there is placed a loading of a cheap grade of Portland-cement concrete, sufficient to resist the upward pressure of the water, which is, on the horizontal layers, about 500 lbs. per square foot, this pressure being dependent, of course, on the elevation of the sheet, with reference to the ground-water level. In some places the weight of the walls is far in excess of the water pressure; in others, where possible, the pressure is resisted by inverted concrete arches.

A drain-pipe channel underlies each loop track for its entire length, and these discharge into the sump well near the power-house, where both rain water and any leakage through the waterproofing finds its way, either through the automatic tide gates at low tide, or is pumped at other stages of the tide into the Fort Point Channel. The tarred paper is introduced into the waterproofing sheet to give it a fiber, and the pitch to make it watertight. It was not desirable to have the sheets of paper of great thickness, as that would permit the paper to split in its own thickness, but rather a thin paper, which would saturate to a greater extent, and to make up for thickness by a greater number of sheets, the total number being a matter of judgment. The coal-tar pitch should spread under pressure, and when warmed in the hand should spin out as fine as a hair. This combination of pitch and paper was selected in preference to a layer of asphalt, as it could be bent, twisted, knuckled, abused and handled more readily than the asphalt, which, if disturbed very much, it was thought, would crack clear through. It is not believed that the pitch will volatilize in its secure position away from air. Up to the present time no leakage in this great area has been discovered.

The waterproofing work was carried on regardless of the temperature. An 8-in. brick wall was found to be the most suitable backing where the sheet is brought up back of the walls. Care had to be taken that the walls should not slide sideways upon the pitch before the concrete bracing in front was in place.

To determine the pressure likely to be exerted on the under side of the waterproofing sheet, the following line of reasoning was used:

	Elevation.
Mean high-water level is about	10.00
Extreme high-water level (during a severe storm in 1851) is registered as	15.74
Mean low-water level is about	0.00
Extreme low-water level is about	—3.00
Ground-water level some distance back from the water front, by observation, is about	9.00

showing that high tides do not remain up long enough to penetrate any great distance through the ordinary earth filling.

As the sheet-pile cofferdam, with the top at elevation 16.00, put in to enable the work to be carried out, was to be left in the ground,

it was reasoned that extreme high tides would not penetrate beyond the dam, and therefore that an assumed elevation of 12.00 would be safe for any possible condition. Had the coffer dam entirely surround the site, it is quite likely that water would have risen inside of the dam to the top of the sheathing, but as the dam does not extend entirely around the work there is ample opportunity for the ground-water to stand at its usual level.

Having assumed the water level at elevation 12.00, as giving the maximum hydrostatic pressure, it only remained to calculate the required loading of concrete for any given level of the waterproofing sheet. To distribute further any load from columns over the sheet as as far as possible, old steel rails were introduced into the concrete wherever it was possible. These are shown in the various sections. In the case of the light loading under the loop-tracks they were used to distribute a surplus loading on either side to the area under the tracks. They are also placed under the retaining walls so as to project as far as possible.

Piling.

All the piles used have been of spruce, varying from 25 to 40 ft. in length, with a minimum of 12-in. butts and 6-in. tips. The specifications called for these to be driven their full length into the ground, or until the penetration should not exceed 12 ins. in twelve blows from a 2 000-lb. hammer falling 20 ft., with the hammer line attached, or its equivalent. The spacing generally has been 2 ft. 6 ins. center to center, and in some places a little less. The loading has ranged between 8 and 10 tons per pile, which is reasonable in friction ground, and with piles of the above character. In some places the penetration was from 3 to 8 ins. at the last blow, and where this occurred, additional piles were used to reduce the loading. In all, about 13 000 piles have been used. The cost has varied from $3.10 to $5.00 each, in place, depending upon the length.

Concrete.

Three different classes of concrete have been used in the work.

First.—Ordinary natural-cement concrete, one part cement, two parts sand and five parts screened gravel.

(In all cases on this work screened gravel was specified in order to avoid sharp stones against the waterproofing sheet. Experience,

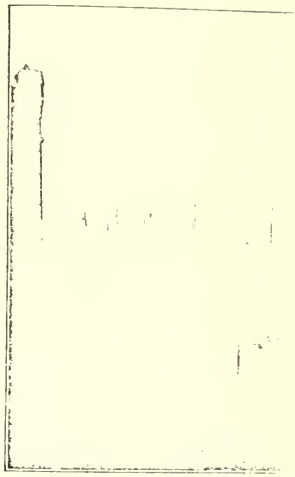


Fig. 1.—General View of

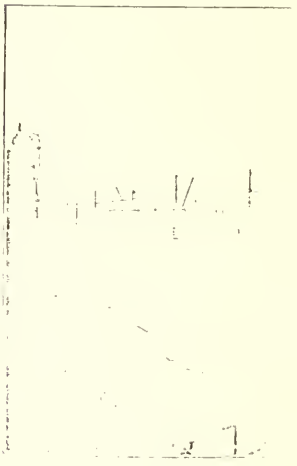


Fig. 2.—General View

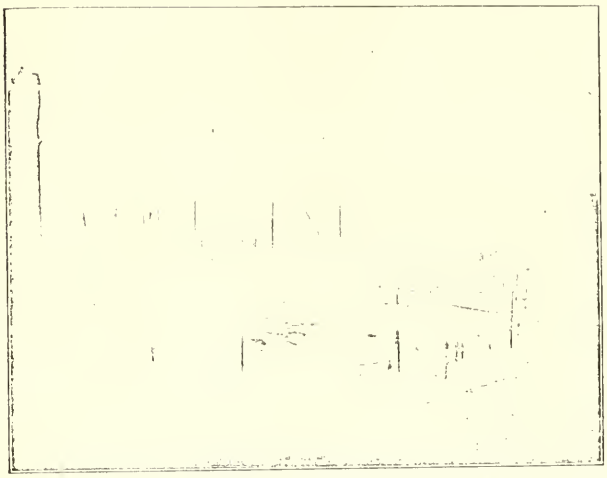


FIG. 1.—GENERAL VIEW OF WORK, FEBRUARY 10TH, 1898.

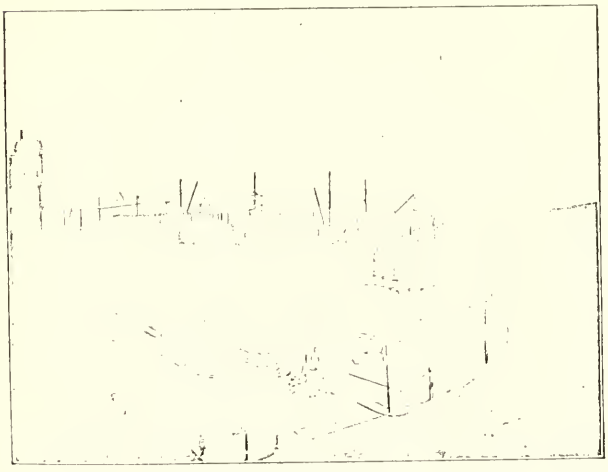


FIG. 2.—GENERAL VIEW OF WORK, APRIL 11TH, 1898.

however, has shown that this was not absolutely necessary. This has been used for backing masonry in granite-faced walls, and was specified on account of the necessity of having a smoother surface on the rear of the walls against which to build the water-proofing sheet. It was discovered, however, by the contractor's men, that they could lay up a very smooth face out of rubble granite and mortar when required for the waterproofing sheet, and at about the same cost. This was allowed in places, as it made a slightly heavier and better wall when well done. Had the smooth-backed rubble wall been specified, it doubtless would have raised the price of rubble over concrete, on account of the prospect of the contractor having to build a double-faced wall, but when the trial was made it was found that the difference in cost was insignificant, as the workmen soon adapted the work to the requirements.

Second.—Portland-cement concrete, one part cement, two parts sand and five parts screened gravel.

This has been used where it became a part of a foundation to support columns or piers, where it was the foundation support for the waterproofing sheet, where used as an inverted arch, and in places where it was necessary to deposit concrete in water.

Third.—Portland-cement concrete, one part cement, three or four parts sand, and six or seven parts screened gravel, the proportions depending on the size of the individual pieces of gravel.

This was used as a loading for the waterproofing sheet, and was meant to be only a reasonably stiff loading, but it has proved to be almost as hard as rock, and cannot be cut or broken except with stone-cutting tools. In a few instances concrete of this class was used as a backing for walls, rather than cause delay by waiting for the usual material. When used as a waterproofing loading, it was not rammed as hard as otherwise, as it was desirable that seepage water should find a way to drains provided, without coming to the surface. Nearly all the concrete used on this work was mixed in a Cockburn Barrow & Machine Company concrete mixer. The work was carried on regardless of temperature, and in cold weather no special provision was made except to thoroughly heat the water, sand and gravel before mixing, which was done by steam pipes in large bodies of the material. The cost of the concrete has varied from $3.30 to $5.00 per cubic yard, according to classification and contract.

Cement.

The Portland cement used throughout the work was the Alpha brand of American Portland cement. The masonry and concrete in the work required a large quantity of cement, but did not demand that an extra fine quality be used, as might be the case with work done under running water. Specifications were purposely drawn to admit the use of any good average brand, foreign or American, either slow or quick-setting, with the object of opening the bidding to lively competition and a low rate. The specifications required, for Portland cement, a tensile strength of 200 lbs. per square inch in 24 hours, having stood in air until set, and the remaining time in water; and for natural cement, a tensile strength of 100 lbs. per square inch when tested in the same manner.

This method secured the cement at very low rates. About 75 000 bbls. of Portland cement and 20 000 bbls. of natural cement have been used, and, in the case of the Portland, it is believed that nearly $1 per barrel was saved over what would have been the price if a rigid specification had been adopted and a limited number of brands allowed.

A great many tests for tensile strength were made, and in no case was it necessary to reject cement. Owing to the large consumption of the mill product, only a small amount of cement could be kept on hand, and it was impracticable to make more elaborate tests before the cement was used in the work.

The proof that the cement is of a most excellent quality lies in the actual character of the concrete after it was put in place, even the poorest quality of concrete, consisting of ten parts of sand and screened gravel to one part of cement, requiring the use of hand stone-cutting tools where it has been necessary to open it for pipe ducts or other purposes.

Owing to the reduction in the cost of manufacture, and the ability to use Portland-cement mortar in zero weather without injury, and also the possibility of obtaining excellent mortar with a very small proportion of cement, making the cost of work done on a par with natural cements, the tendency to use Portland cement exclusively will undoubtedly increase very rapidly.

PLATE X.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XLIII, No. 870.
FRANCIS ON BOSTON SOUTH TERMINAL.

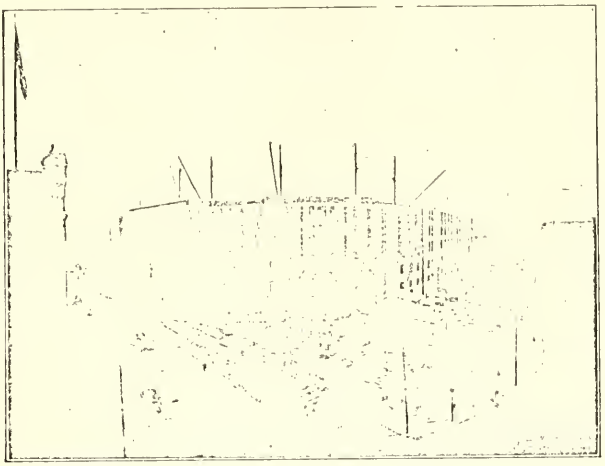


FIG. 1.—GENERAL VIEW OF WORK, JUNE 20TH, 1898.

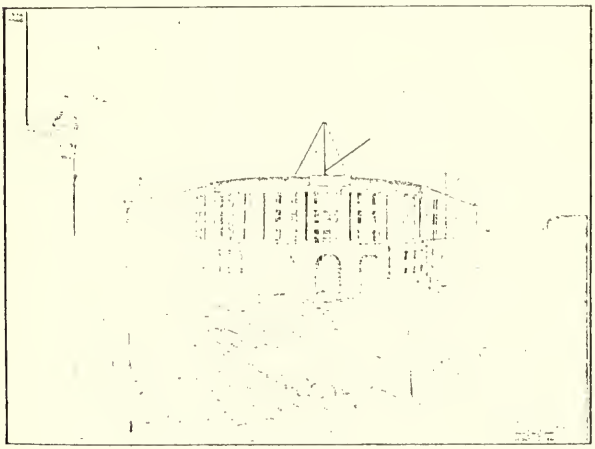


FIG. 2.—GENERAL VIEW OF WORK, AUGUST 24TH, 1898.

Stone.

Of course, in eastern New England, granite is about the only stone which can be obtained in large quantities for building purposes, and granite was used throughout in all foundations and retaining walls. For the face of the walls of the subway and the train-shed piers, the specifications required that they should be laid in courses varying in height from 15 to 26 ins., alternating header and stretcher work, headers never narrower than their rise and 5 ft. long, if the wall would permit; stretchers limited to 8 ft. long, beds to be as wide as the rise, to be without slack spots of greater depth than 1 in. All joints to be not more than 1¼ ins. for a distance of 12 ins. back from the face. On account of having a granite face and generally a concrete backing, two prices were used, one for face and one for backing. The face masonry has generally cost a little less than $10 per cubic yard.

The granite used in the work was brought from the following quarries: Stony Creek, Conn.; Milford, Mass.; Rockport, Cape Ann, Mass.; Pigeon Cove, Cape Ann, Mass.; Mt. Desert, Me.; Croaeher's Island, Me.; Deer Island, Me.; Northbridge, Mass.; Fitchburg, Mass.; Pascoag, R. I., and Milford, N. H. In addition to this, large quantities of granite from Quincy, Mass., found in the old work, were used again.

Construction Drawings for Piling, Masonry and Tracks.

A scale of one-eighth of an inch to a foot was adopted for pile, masonry and track plans. This divided the work into a number of sectional sheets about 4 ft. wide and 8 ft. long. The longitudinal direction of each sheet took in the entire width of the property. The architects' drawings were also made on the same scale.

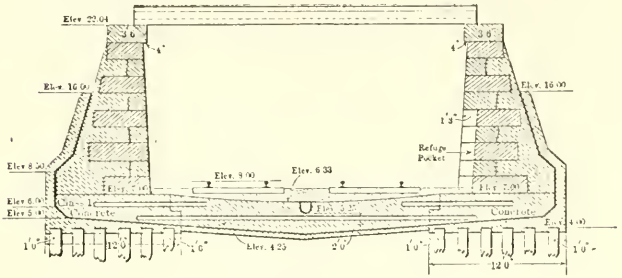
A main base line was adopted and stationed on the longitudinal axis of the train shed, and cross-sectional base lines at intervals of 100 ft. were set out on the ground. All primary locations were made as so much right or left from stations on the main base line.

The first series of plans covered the pile-driving. Each pile was shown, and upon an office blue print the result of each day's work was marked off, and a summary tacked on to the progress sheet.

The second series of plans covered the foundation masonry. Sufficient sectional plans were made on these sheets to illustrate the details, and they were complete in every respect, serving to govern the execution and laying out of the work.

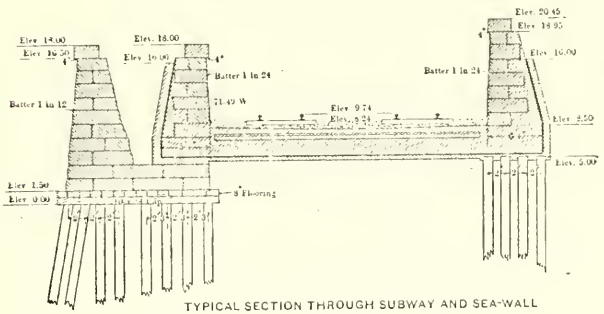
A third series covered the track work, and showed the station of each switch point, frog point, point of curve, apex, grades, each switch tie, interlocking supports, signal posts and bridge supports, and, in fact, everything necessary to make a quick field layout of the ties and tracks.

These plans, being all on the same scale, could be laid over one another, and any important discrepancy be detected instantly. No



STANDARD SECTION DOUBLE TRACK SUBWAY THROUGH "PLACE OF REFUGE"

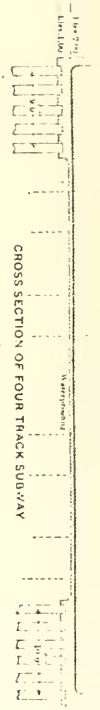
FIG. 1.



TYPICAL SECTION THROUGH SUBWAY AND SEA-WALL

FIG. 2

errors of any moment whatever occurred in the layout of the work, and it was, no doubt, due to the comprehensive manner in which these plans were prepared that such a clear understanding could be had by each workman, and that rapid, sure and economical progress could be made. These plans are so extensive that it is practically impossible to reproduce them for this paper, and only fragments have been introduced.



CROSS SECTION OF FOUR TRACK SUBWAY

FIG. 3.

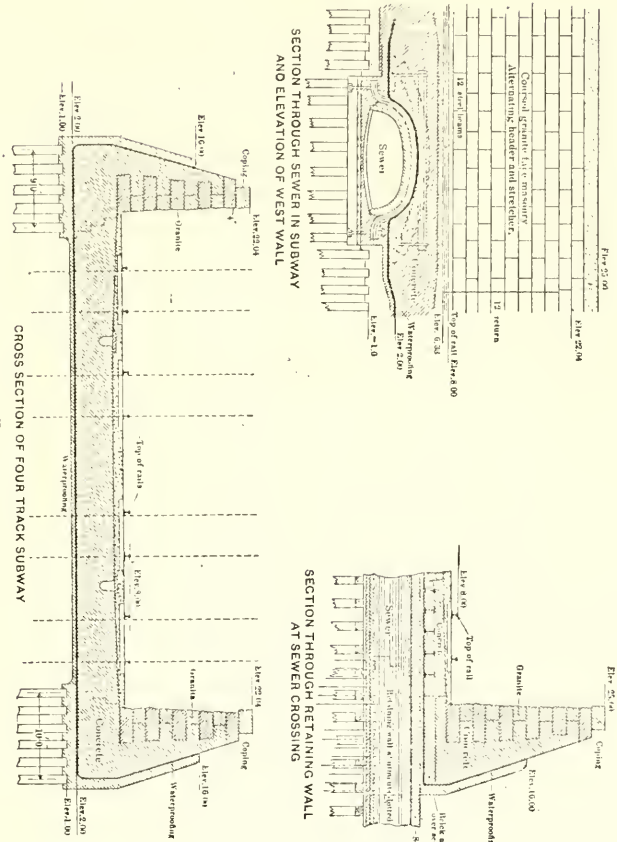

SECTION THROUGH SEWER IN SUBWAY
AND ELEVATION OF WEST WALL
SECTION THROUGH RETAINING WALL
AT SEWER CROSSING
CROSS SECTION OF FOUR TRACK SUBWAY
Granite
Coping
Waterproofing
Concrete
Sewer
Trap of rail
Elev 25.00
Elev 25.04
Elev 16.00
Elev 6.34
Elev 6.90
Elev 2.00
Elev 1.0
Elev 0.00
Elev 10.00

FIG. 3.

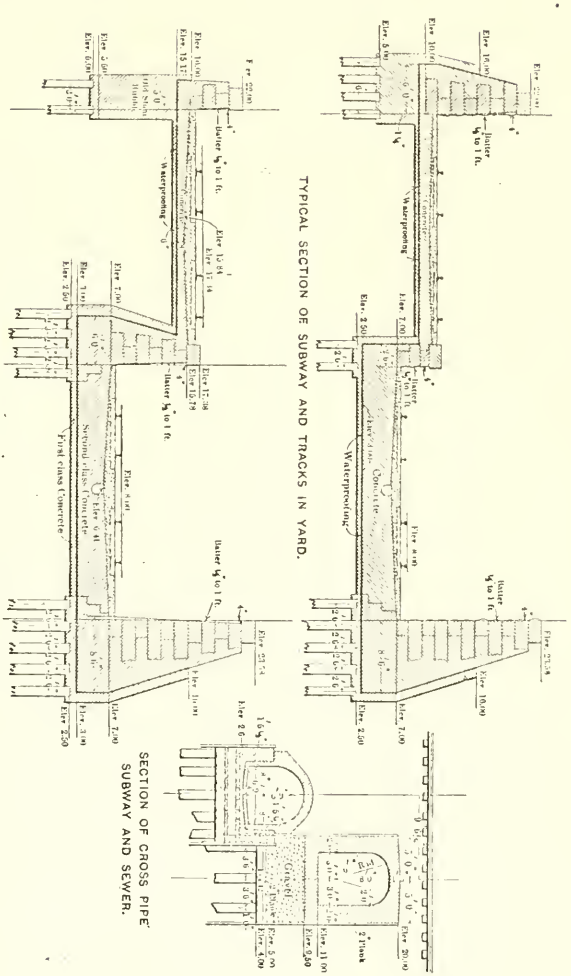

TYPICAL SECTION OF SUBWAY AND TRACKS IN YARD.
TYPICAL SECTION OF SUBWAY TRACKS AND SUPPORTS IN YARD.
SECTION OF CROSS PIPE SUBWAY AND SEWER.

FIG. 4.

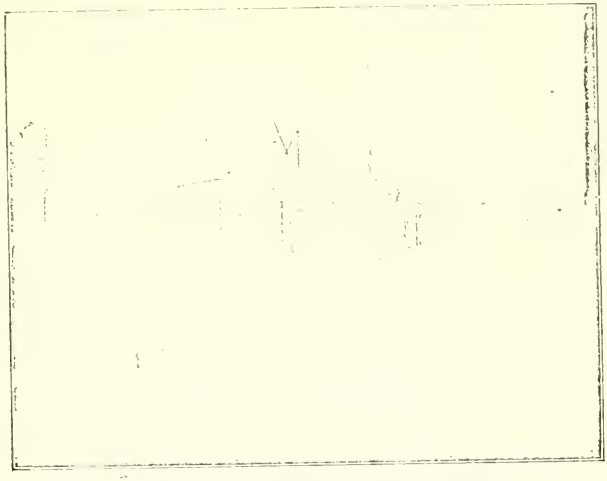


FIG. 1.—GENERAL VIEW OF WORK, OCTOBER 24TH, 1898.

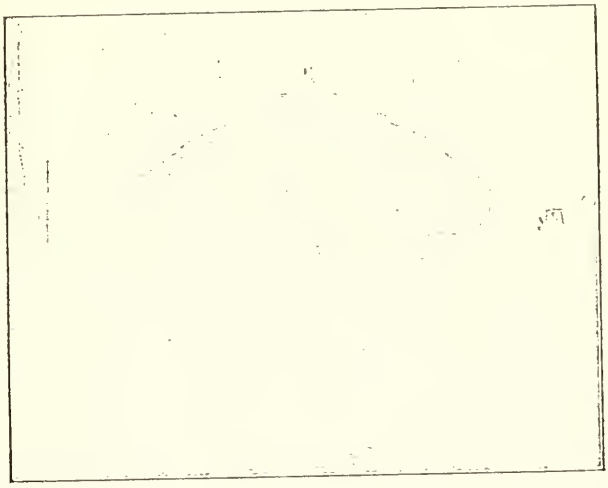


FIG. 2.—GENERAL VIEW OF WORK, DECEMBER 27TH, 1898.

Track Arrangement.

Not the least of the station problems most vital to the successful operation of the station is the track arrangement necessary just outside of the station for the safe and expeditious handling of the trains. It is believed that the arrangement adopted is simple and ample. By it the station may be operated as a unit, incoming trains on one side

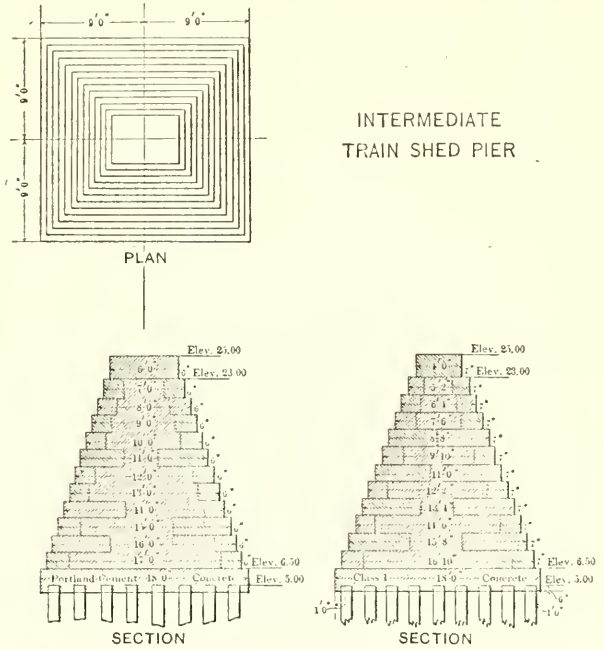


Fig. 5.

and outgoing trains on the other side, or in four sections, one for each of the four main lines. There are eight parallel main tracks, two for each of the main lines, through the throat of the yard; and, to enable trains to pass from either side of the throat to the other side there are two parallel tracks crossing the mains from either side in the shape of an X, or, as it is called, a double-track scissors-crossing, through the

eight main-yard tracks. Another single-track scissors-crossing, through the four main tracks, is provided for the subway or loop-track system.

The distance between the head house site and the Fort Point Channel, also the curved tracks connecting two of the main lines, was not great enough to permit of as easy curves for the development of the eight main tracks into the twenty-eight train-shed tracks as was desirable, but these curves have been kept down to a minimum radius corresponding to 10° curves.

The express-yard tracks have been arranged to give the greatest length of track opposite platforms, and, at the same time, to permit of shifting cars with as little disturbance of other cars as possible. Other yard-tracks are arranged to suit the various desires in yard work.

Number eight frogs have been used for the main-track crossings and for nearly all the regular turnouts on the main yard lines.

Number six frogs have been used for the subway crossing, and in certain places in the yards.

The express buildings were placed upon the westerly side of the yard, and the power-plant buildings upon the easterly side, this arrangement seeming best for each service.

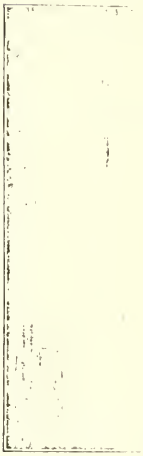


Fig. 1.—Pile Test.

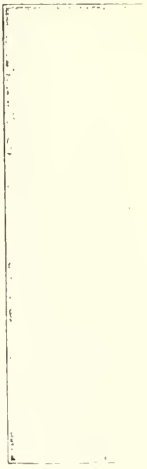


Fig. 2.—Piers and Columns on West Side of Train Shed.

Platforms.

With the exception of the two exterior tracks on each side, the tracks are spaced 23 ft., center to center, making the passenger platforms 14 ft. wide. There are two passenger platforms, one on each side of the shed, 23 ft. wide, with track spacings of 32 ft., center to center.

The baggage platforms are 8 ft. wide, track spacing 17 ft., center to center. The arrangement for baggage handling is such that there are nine baggage and express trucking platforms the entire length of the train shed, independent of the passenger platforms, and an underground passage to allow the baggage trucks to cross beneath the tracks. This method, which it is believed will very much reduce the baggage nuisance generally experienced, required seventeen baggage and express lifts, eight in the train house, four in the baggage rooms, and five in the express buildings. Those in the baggage platforms are protected with iron fences and gates with automatic attachments. These lifts are described, together with the other electrical and mechanical features of the power plant, in another part of this paper.

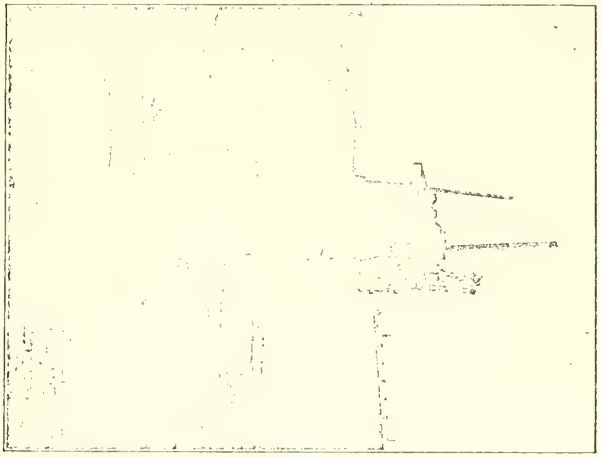


FIG. 1.—PILE TEST.

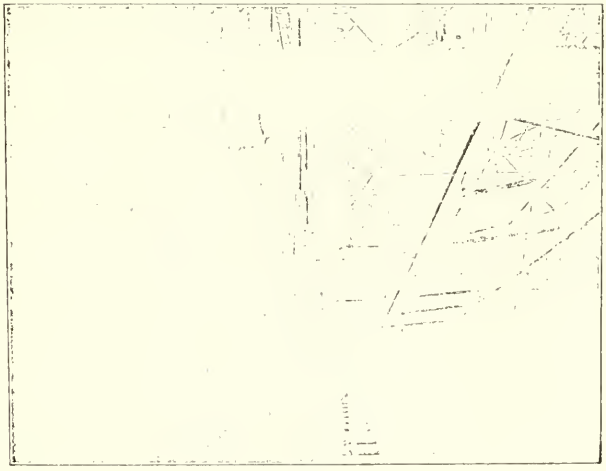


FIG. 2.—PIERS AND COLUMNS ON WEST SIDE OF TRAIN SHED.

Some of these platforms extend about 300 ft. beyond the end of the train shed, making them 900 ft. long. They were built of timber (hard pine), surfaced, 2 x 4 ins., and tongued and grooved, for a first construction, on account of the tendency of the newly filled material to settle irregularly over the old piers and docks. Eventually it is intended that they shall be granolithic. They are so constructed that, by removing cleated sections screwed down over the sills, they can be tamped up, similar to track, from time to time.

Rail.

The track rail used throughout the terminal is the New York, New Haven and Hartford Railroad standard, 100-lb. rail, $5\frac{1}{2}$ ins. wide and 6 ins. high, with rail head $2\frac{3}{4}$ ins. wide.

Frogs and Switches.

All regular turnout switches have points 15 ft. long and five bridle rods, connected to clips with turned bolts, nuts and cotter pins. Clips are connected to webs of rails by two bolts.

Slip switches have points 15 ft. long for the number eights and 15 ft. long for the number sixes, with four bridle rods, fastened as indicated above.

All slip crossings have a $\frac{5}{8}$-in. x 7-in. steel plate on each tie from end to end, and one tie beyond.

All slip crossings have movable frog points (with two bridle rods), 10 ft. 10 ins. long for the number eights and 8 ft. 4 ins. long for the number sixes. All other frogs are rigid bolted frogs.

Guard rails are 10 ft. long.

In the diamond crossings, the rails are double for practically the entire diamond. All switches and frogs were made by the Ramapo Iron Works.

Bumping Posts.

There are 54 Ellis patent bumping posts, all equipped with the standard 100-lb. rail.

Ballast.

All the ballast in the subway and its approaches is a broken trap-rock ballast from Meriden, Conn. All other ballast is ordinary gravel ballast.

Ties.

All regular 8-ft. ties are of chestnut timber, 6 x 8 ins., and all special ties are Georgia hard pine, sawed to dimensions, generally of 7 ins. depth by 9 ins. face, except some ties with 10 ins. depth for special places.

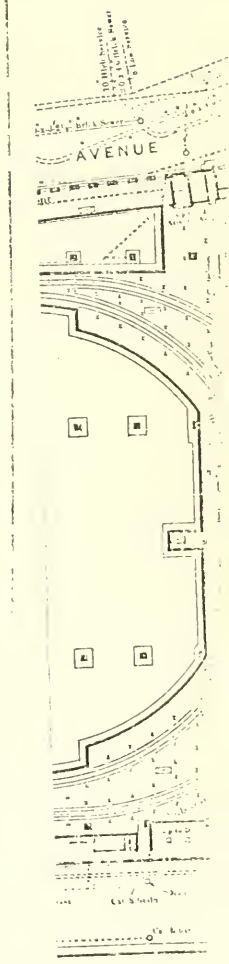
No tie preservative has been used. Upon all curves the Goldie tie-plates have been placed, and, wherever necessary, substantial cast-iron rail braces have been used.

Steel Flooring.

The "Thomson" shape, or rectangular trough floors were adopted in preference to any type of floor with flaring sides, on account of the necessity of spanning the subway tunnel with the thinnest possible floor over all. Girders could not be arranged so as to come up between the ties, due to the various skew positions of the subway, therefore a floor of shapes with small depth could not be made on account of the span, which was 28 ft. in the clear. The troughs are made in about 18-in. depths, and, in order to get sufficient flange metal, cover-plates are used. The design is such that if at any time in the future the position of the tracks is altered, no alteration will be required in the floor. Impact allowance was disregarded in the floors in the train shed, as the speed of trains there cannot be great. Having adopted this type of floor on the greater portion of the area, it was thought best to continue its use over the remaining portion. The weight of the floor girders, columns and troughs complete is 94 lbs. per square foot. Ventilation from the subway tunnel is arranged for through the ends of the inverted troughs, and cast-iron grating ventilators in the baggage platforms over the lines of the retaining walls.

The entire top of the steel troughs and girders, after being painted with two coats of red lead and oil paint, are swabbed with an asphaltic swabbing material, costing about 15 cents per horizontal square yard of floor, according to the following specification:

"Swab the entire upper surface, vertical and horizontal, of all the steel trough floors with one coat of mineral pitch and oil put on at a temperature of about 350° Fahr., and mixed in a proportion of about 85% of mineral pitch (commonly called 'Trinidad Asphalt') and 15% of crude black oil (residuum of petroleum), if applied in warm weather,



BASEMENT PLAN
OF
TERMINAL STATION
AT
BOSTON, MASS.
FOR THE
N.Y.N.H.& H. AND B.& A.
RAILROADS.

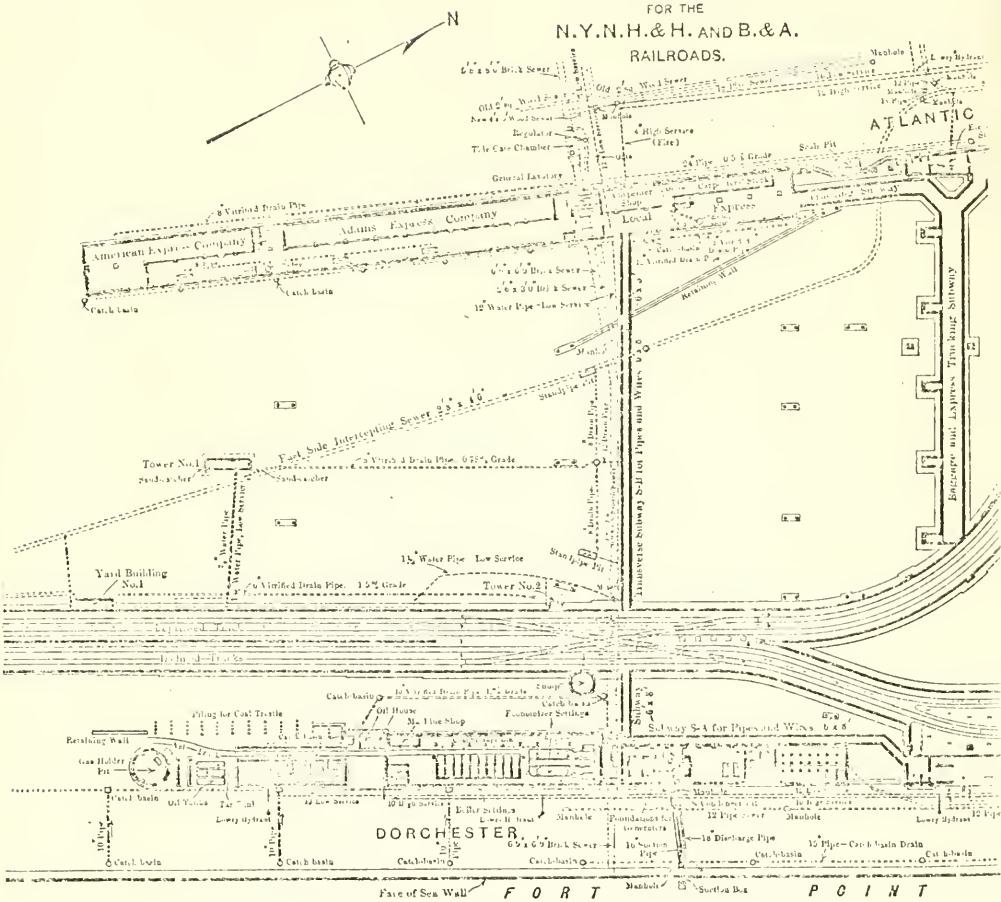
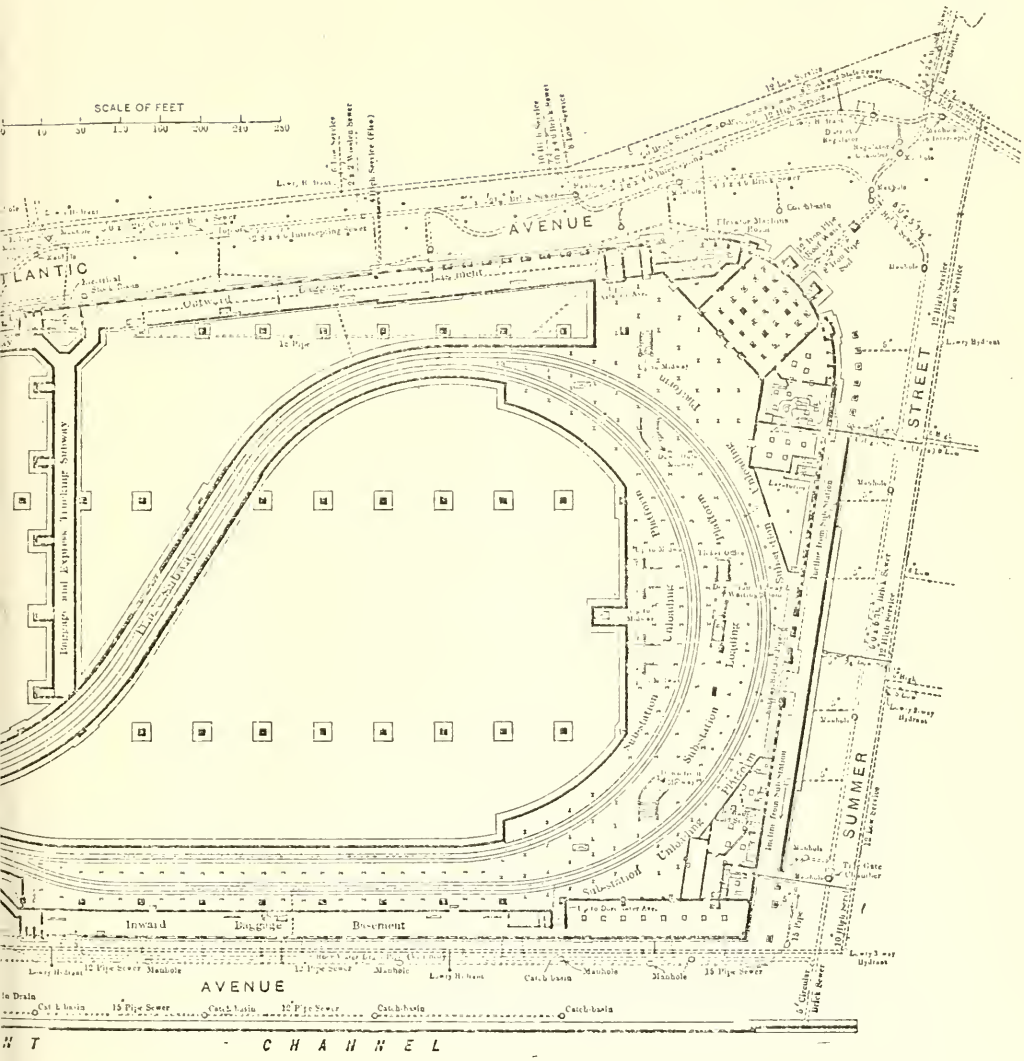


PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XLIII, NO. 870.
FRANCIS ON BOSTON SOUTH TERMINAL.



or of about 65% of mineral pitch and 35% of crude black oil if applied in cold weather, varying the proportion within these limits to suit the temperature. In warm weather the swabbing on vertical and inclined surfaces to be done only a small amount in advance of the ballast work, on account of the tendency of the mixture to crawl, under a hot sun. The mineral pitch to be either the trade article known as 'Refined Trinidad Lake Asphalt,' which contains no oil, or the article known as 'paving cement,' which is the same with an addition of about 15% of oil, and which oil shall be considered a part of the above-named oil proportion or percentage. The swabbing mixture to be prepared and heated in kettles at the site of the work. All troughs and iron to be swept clean before being treated, and no work to be done in the open air in wet weather. No gas-tar or other preparation to be used. Where steel flooring joins girders, or at other open joints, an asphaltic mastic shall be used to close the openings in a thorough manner."

Upon this swabbing the gravel ballast is deposited. The design of this swabbing is to coat the steel with a substance oily in its nature, many times thicker than any paint, and to thereby keep the water away from actual contact with the steel as long as possible. It was not advisable to place this swabbing coat where it could escape through the open connections, as it has a tendency to run in hot weather, causing an unpleasant appearance where it shows below.

Midway Floor.

The space between the head house and the train shed proper, called The Midway, is directly over the suburban station, and this area is supported on steel columns. Brick arches, with enameled brick lining, are turned from beam to beam, as a suitable ceiling for the suburban station. Upon the top of the arches, the floor is leveled up to the underside of the asphalt surface with a concrete made up of one part Portland cement, five parts fine cinders and ten parts coarse cinders. The asphalt surface is the usual Barber asphalt pavement, made of Trinidad Lake asphalt. This was laid 2 ins. thick, at a temperature of about 250° Fahr., and was rolled to a hard surface with a steam road roller. This floor is 610 ft. long and averages 90 ft. wide. No provision was made for expansion and contraction of the steel girders and beams, and there is no evidence of movement in either the steel or the asphalt floor. The expansion of each piece of steel is apparently taken up in the riveted joints. This floor has an inclination of 1 ft. between the end of the train shed and the rear of the head house.

Midway Fence.

The midway fence is a wooden, round-picket fence, 9 ft. high. The posts are fastened at top and bottom. The gates are in two parts, rolling back on the fence, making openings 12 ft. in width, opposite each passenger platform. These passageways are very liberal for crowds, and the fence, taken altogether, finished in natural wood, makes a very neat appearance.

Train Indicators.

Upon this fence, against posts set for the purpose, opposite the ends of each of the twenty-eight tracks, are the train indicators, 6 ft. wide and 9 ft. high; all but two carrying four columns of station names, amounting to about seventy-four names for each indicator. They also give the track number, name of the road, and the leaving time, and are worked by a sort of interlocking machine. Each train is represented by a card, perforated for all stations except those at which the train stops. This card is inserted in the machine and raised with a lever, moving the rods (except at the perforations), which turns the slats on the indicator. These indicators were made by the Wheeler and Wilson Manufacturing Company, Bridgeport, Conn., and are the largest ever made for the purpose.

Train-Shed Steel.

The train shed proper is a rectangular building 602 ft. long and 570 ft. wide, divided into three spans, 169 ft. 9 ins., 228 ft. 6 ins. and 169 ft. 9 ins., respectively. The trusses are cantilevers, and this form reduces the connecting trusses in the middle span to 145 ft. $6\frac{5}{8}$ ins. The irregular-shaped areas between the train shed and head house (irregular on account of the lay of the streets), both on the end and sides, are covered by connecting roofs, that at the end being called the midway roof.

The midway roof and the other connecting roofs are not as high as the eaves of the train shed proper, and, therefore, there is a row of high windows on the sides of the train shed for the entire length. Both gable ends of the train shed are filled with windows. There is a central longitudinal main monitor 60 ft. wide, in the sides of which are both windows and louver ventilators, and on top of which there

is a louvered ventilating monitor 16 ft. wide. Over each intermediate truss, on each slope of the main roof, are cross-monitors about 14 ft. wide, reaching from near the eaves to the main monitor. These cross-monitors have windows and also louvered ventilators in their sides, alternating in the various panels. There are no windows or skylights on the slope of the roofs or monitors, all glass being set on the vertical.

The columns and trusses are placed 60 ft. apart, center to center, longitudinally of the shed. The side columns are in box form, and are anchored to the masonry to resist wind pressure. The intermediate columns are not thus anchored, except at the end panels, but carry the major part of the weight of the roof.

The cantilever type for intermediate trusses permitted the making of an arch form to the various spans without unduly increasing the weight of the trusses. This arched form could not have been obtained without the cantilever principle, except at considerable expense for extra weight of metal. All the train-shed trusses are pin-connected.

At each panel point in the trusses is inserted a vertical web member, against which are fastened the purlins, so that all the purlins, which are riveted triangular trusses about 7 ft. 9 ins. deep and 20 ft. apart, stand in a vertical position. Upon these purlins are small I-beam jack-rafters, 7½ ft. apart.

Beginning at each end of the shed, the trusses and columns are braced longitudinally in pairs, until the center is reached, where three trusses and columns are braced together. At the end pairs, the longitudinal bracing is brought to the ground. The end trusses are not cantilevers. The longitudinal expansion and contraction is taken care of between the braced pairs of trusses. The transverse expansion and contraction is taken care of in the intermediate trusses, at the end of one of the cantilevers, on a hinged post, acting as a vertical link; and at the end trusses by supporting the foot of the inclined end post by eye-bar hangers inside of one of the intermediate end posts, the movement in the roof covering taking place at the top of the inclined end post, which is on a line with the ends of the cantilevers. The roof covering is made tight at the expansion joints by simply lapping the higher portion of the roof covering over the lower portion. On the sides and top of the cross-monitors, and at the ends of the shed, a similar lap in the covering is made. At the lower chords of the end

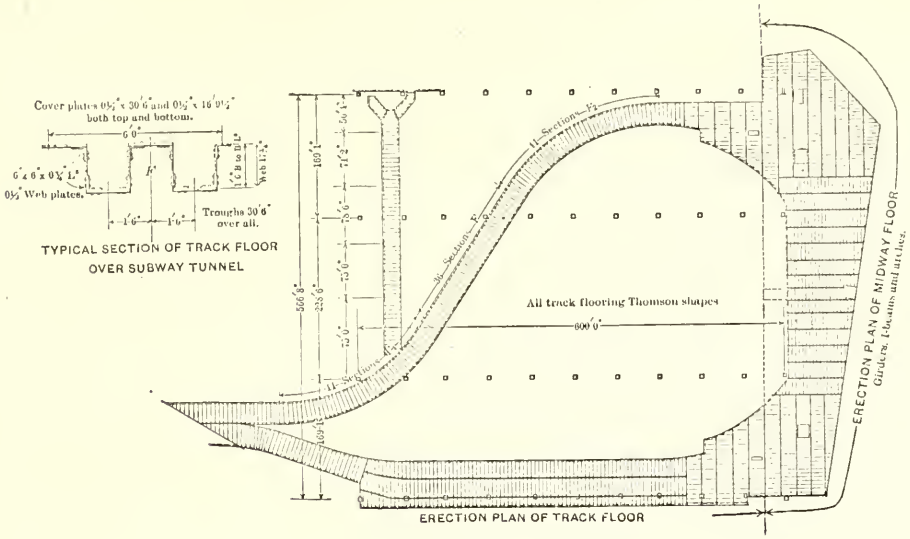

Cover plates 0½" x 30'6" and 0½" x 16'0½" both top and bottom.
6'0"
6" 6" x 0½" L's
0½" Web plates.
Troughs 30'6" over all.
1'6"
1'6"
TYPICAL SECTION OF TRACK FLOOR OVER SUBWAY TUNNEL
All track flooring Thomson shapes
800'0"
II—Section—II
ERECTION PLAN OF MIDWAY FLOOR
Girders, I-beams and struts.
ERECTION PLAN OF TRACK FLOOR

FIG. 6.

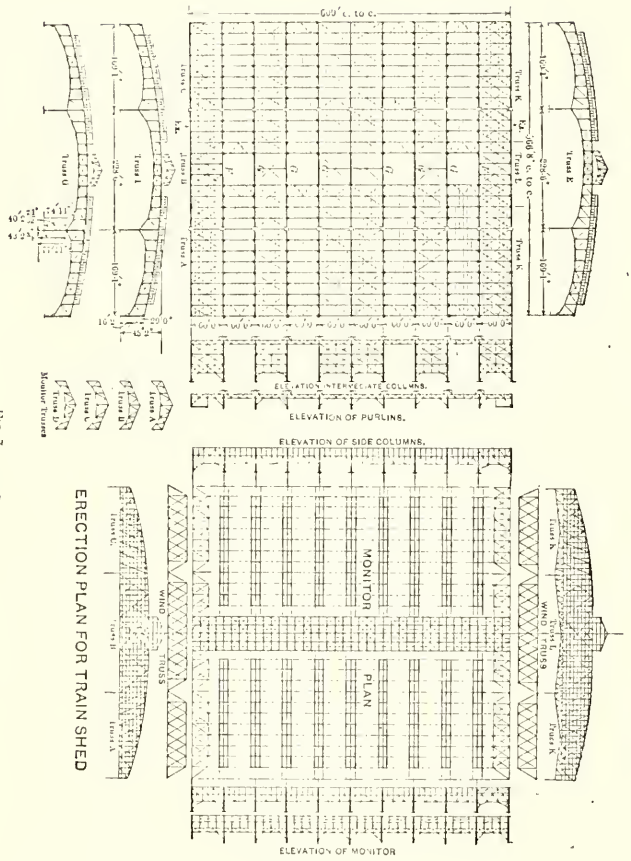
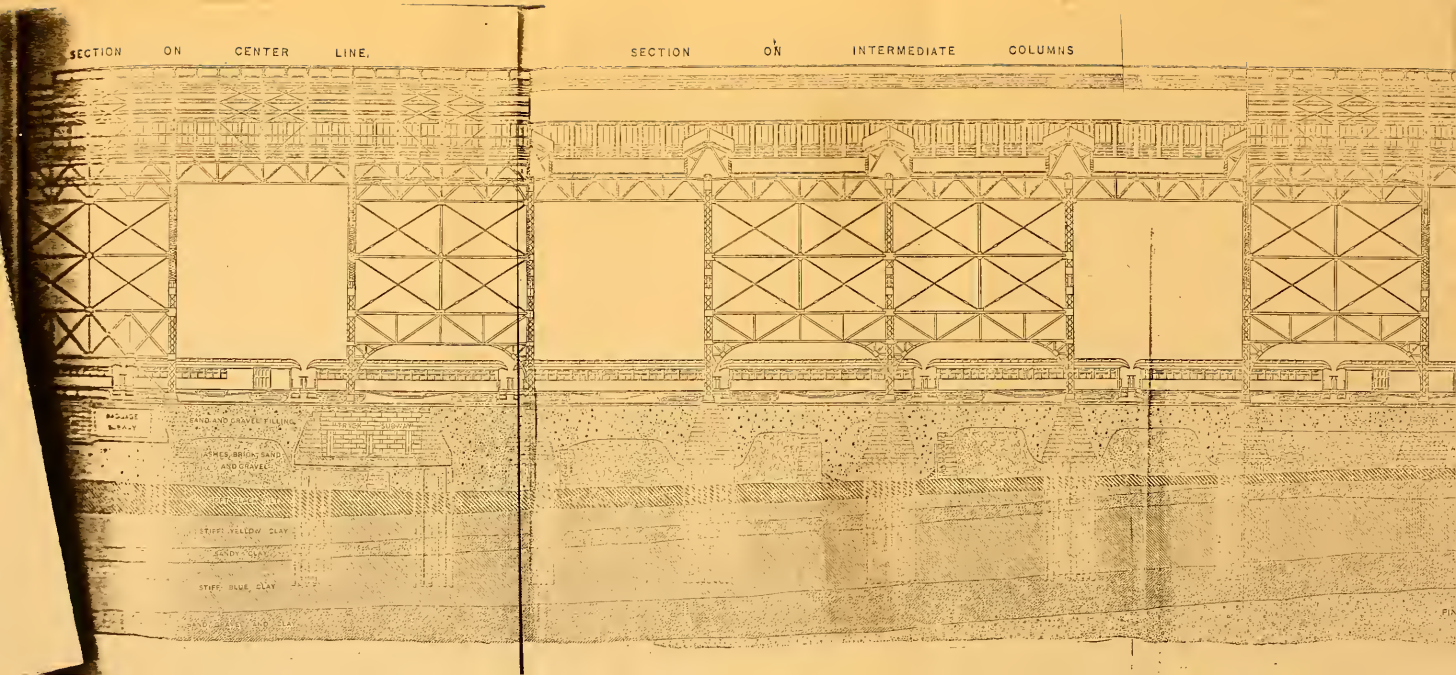
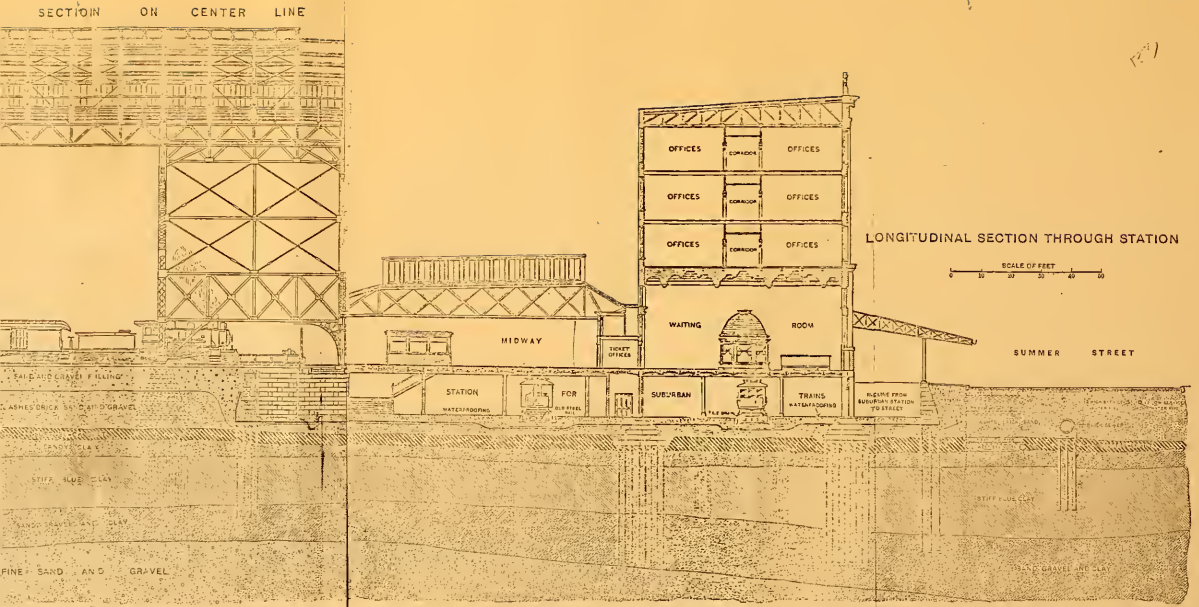

600' c. to c.
Truss O
Truss I
Truss K
Truss E
Truss A
Truss N
ELEVATION INTERMEDIATE COLUMNS.
ELEVATION OF PURLINS.
ELEVATION OF SIDE COLUMNS.
ERECTION PLAN FOR TRAIN SHED
MONITOR
PLAN
WIND TRUSS
ELEVATION OF MONITOR

FIG. 7

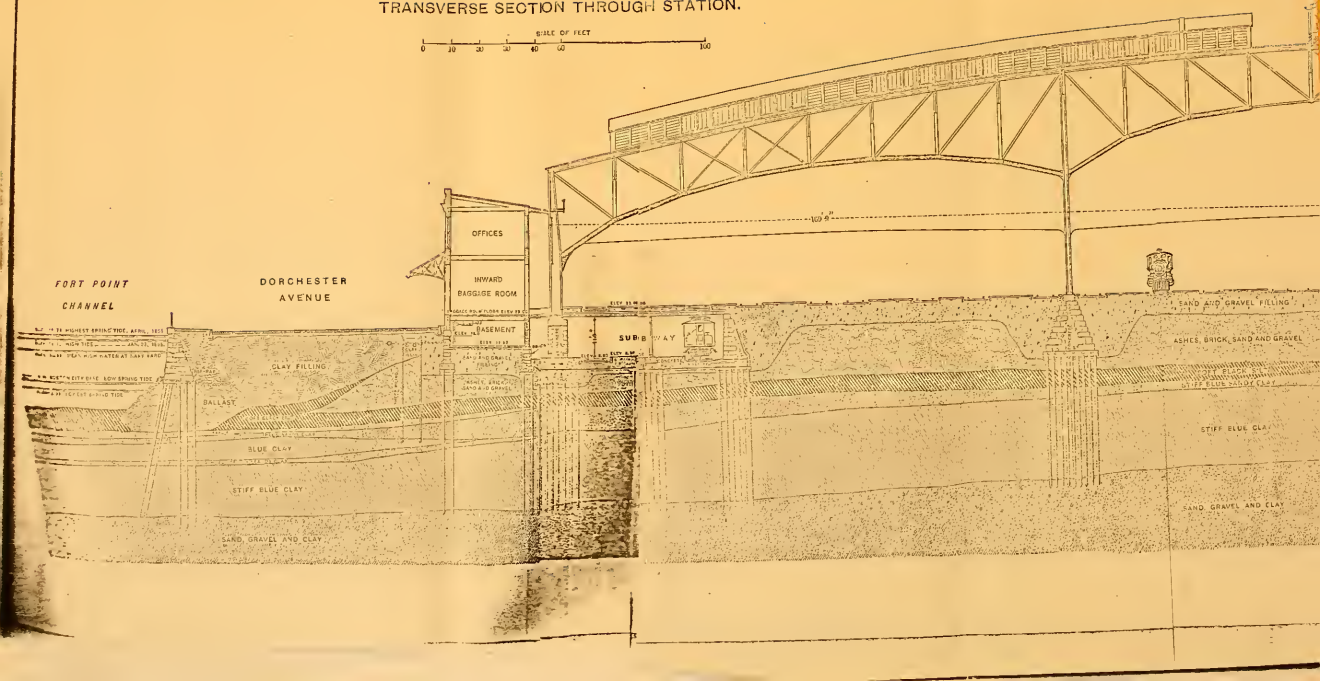

SECTION ON CENTER LINE.
SECTION ON INTERMEDIATE COLUMNS
SAND AND GRAVEL FILLING
STIFF YELLOW CLAY
SANDY
STIFF BLUE CLAY

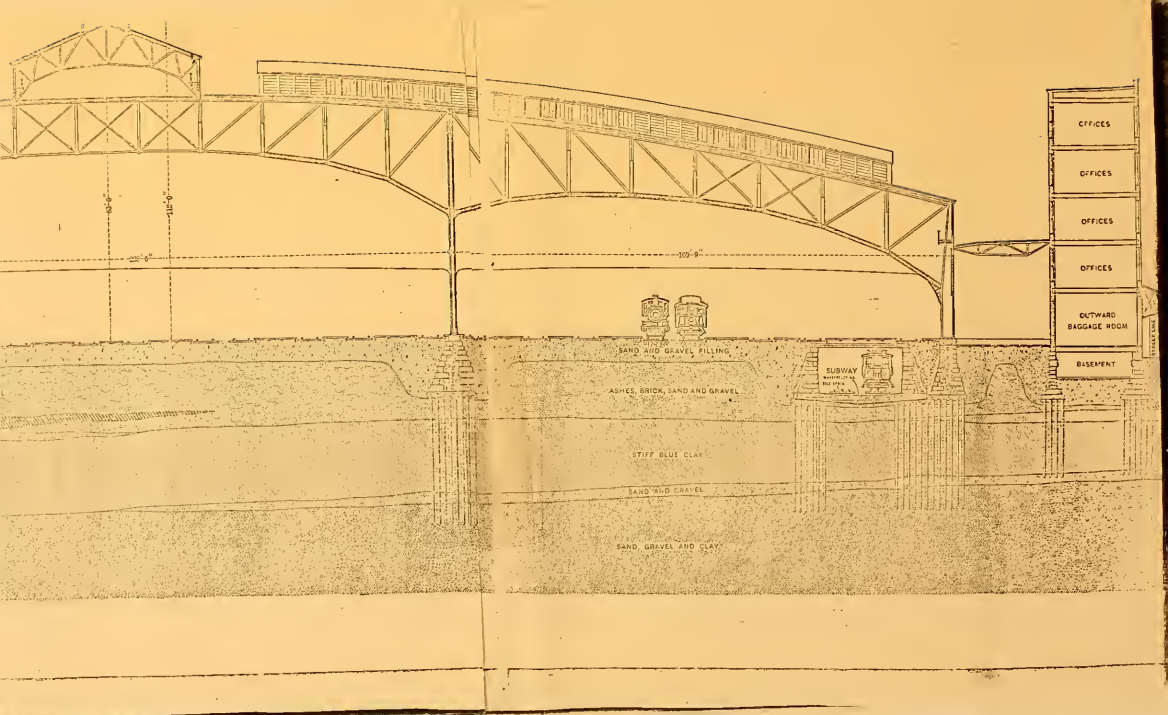

SECTION ON CENTER LINE
OFFICES
CORRIDOR
OFFICES
OFFICES
CORRIDOR
OFFICES
OFFICES
CORRIDOR
OFFICES
LONGITUDINAL SECTION THROUGH STATION
SCALE OF FEET
0 10 20 30 40 50
MIDWAY
TICKET OFFICES
WAITING ROOM
SUMMER STREET
STATION
SUBURBAN
TRAINS
ENTRANCE FROM SUBURBAN STATION TO STREET
STIFF BLUE CLAY
FINE SAND AND GRAVEL

TRANSVERSE SECTION THROUGH STATION.

SCALE OF FEET

0 10 20 30 40 50 100




OFFICES
OFFICES
OFFICES
OFFICES
OUTWARD BAGGAGE ROOM
BASEMENT
SAND AND GRAVEL FILLING
ASHES, BRICK, SAND AND GRAVEL
STIFF BLUE CLAY
SAND AND GRAVEL
SAND, GRAVEL AND CLAY
SUBWAY

trusses there are large horizontal wind trusses with latticed members. The gable ends are also braced by and from the end purlins.

The midway roof is anchored at the head-house end of each truss, and is supported at the train-shed end by eye-bar hangers, indirectly from the lower chord. As these midway trusses are square to the head house and spaced at irregular intervals to suit the pilasters of the head house, they do not come at the panel points of the end train-shed truss, and a stiff horizontal member is placed along under the lower chord of the end truss and fastened to it at the panel points, to give support to the midway truss-hangers at any point.

The conditions which governed the architecture of the midway roof were as follows:

A flat-iron shaped area, with a maximum and minimum width of 130 and 50 ft., respectively; a demand that it should not be high enough to shut out light from the end of the train shed or from the offices in the head house; so arranged that light and ventilation should be had for the main waiting-room; and without any post supports in the midway. It appeared to be

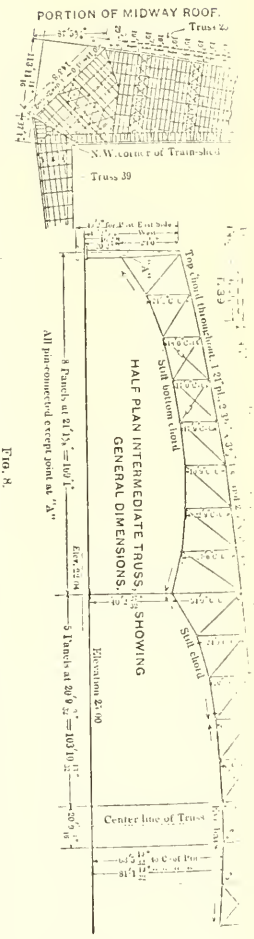


FIG. 8.

necessary, therefore, to adopt a depth of truss which would be suitable for a 50-ft. span, or a 130-ft. span. This resulted in a riveted-lattice truss, with the bottom chord as high as possible, governed by the windows of the waiting-room, and in order to raise the apparent head-room as much as possible, high monitors were placed above the top chords, in the sides of which were placed the windows, which light and ventilate the midway thoroughly. The low appearance of the midway roof has been the subject of some criticism, but in order to meet the practical demands of the surrounding parts of the station, no great variation could be made, other than perhaps a less number of trusses, more purlins, and a more ornamental treatment.

All the connecting roof trusses are of the riveted-lattice type.

The specifications for the steel in these roofs and the flooring was, in brief, as follows :

Open-hearth steel, to contain not more than 0.06% in basic, or 0.08% in acid, of phosphorus, nor 0.05% of sulphur. Ultimate tensile strength to range from 52 000 to 60 000 lbs. Elastic limit not less than 50% of ultimate strength. Minimum elongation of 26% in 8 ins., and a minimum reduction of area of 50 per cent. Rivet steel to have ultimate tensile strength to range from 50 000 to 56 000 lbs., with minimum elongation of 30% in 8 ins., and minimum reduction in area of 60 per cent. For bending tests, the usual requirements for bridge specifications were insisted upon. All the steel was inspected at the rolling mill, and found to be of good quality, calling for very little rejection. The work was oiled and painted with one coat of red lead and oil at the shop, and has had another coat of red lead and oil since erection.

The thankless and hopeless task of selecting a final color, and a paint which will preserve the metal intact and at the same time be beyond all criticism, has not yet been undertaken.

The specifications for loading on the roof and midway floor and tracks were as follows :

First.—Roofs.

Vertical; the dead weight, plus 25 lbs. per square foot of roof surface.

Horizontal; a wind force of 30 lbs. per square foot of vertical surface.

Second.—Midway Floor.

The dead weight, plus 150 lbs. per square foot.

Third.—Tracks.

Dead weight, plus a rolling load for a single-axle load of 50 000 lbs., or axle loads as follows for weights and spacing:

14 000 lbs., 40 000 lbs., 40 000 lbs., 40 000 lbs., 40 000 lbs., 22 000 lbs., 22 000 lbs., 22 000 lbs., 22 000 lbs.; 7′ 0″, 5′ 6″, 4′ 6″, 5′ 6″, 12′ 0″, 5′ 0″, 5′ 6″, 5′ 0″.

Allowed unit strains were, in brief, as follows:

First.—Roofs.

Tension, eye-bars, 16 000 lbs. per square inch.

Tension, built sections and counters, 15 000 lbs. per square inch.

Tension, laterals, 18 000 lbs. per square inch.

Compression, in pounds per square inch:

$$\text{Fixed ends, } \frac{12\,000}{1 + \frac{L^2}{36\,000\,r^2}}$$

$$\text{Hinged ends, } \frac{12\,000}{1 + \frac{L^2}{18\,000\,r^2}}$$

Combined fiber strains from bending and direct strain, and combined direct strain from vertical and horizontal bending.

Tension, 18 000 lbs. per square inch.

Compression, in pounds per square inch:

$$\text{Fixed ends, } \frac{14\,000}{1 + \frac{L^2}{36\,000\,r^2}}$$

$$\text{Hinged ends, } \frac{14\,000}{1 + \frac{L^2}{18\,000\,r^2}}$$

Second.—Midway Floor.

Tension, 15 000 lbs. per square inch.

Compression in columns, in pounds per square inch:

$$\frac{12\,000}{1 + \frac{L^2}{36\,000\,r^2}}$$

Compression flanges, same as tension.

Shear in webs, 9 000 lbs. per square inch, or

$$\frac{12\,000}{1 + \frac{d^2}{3\,000\,t^2}}$$

FIG. 1.—FOUNDATIONS AND WATERPROOFING NEAR MAIN ENTRANCE.

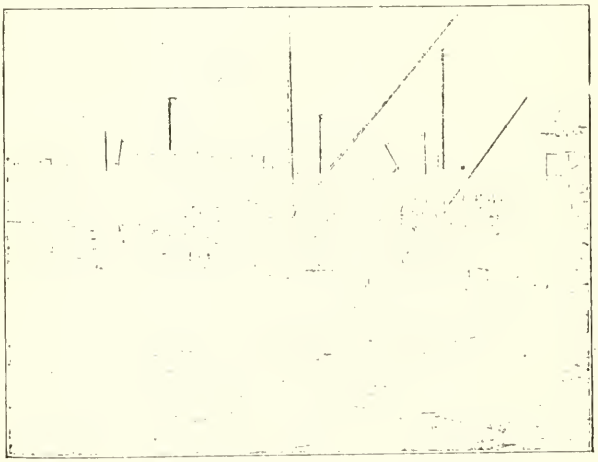


FIG. 2.—BAGGAGE SUBWAY AND WEST SUBWAY.

Third.—Tracks.

Tension, 9 000 lbs. per square inch.

Compression in columns, in pounds per square inch:

$$\frac{8\,000}{1 + \frac{L^2}{36\,000\,r^2}}$$

Compression flanges, same area as tension.

Shear in webs, 7 500 lbs. per square inch, or

$$\frac{10\,000}{1 + \frac{d^2}{3\,000\,t^2}}$$

Bending strains in pins, 20 000 lbs. per square inch.

Bearing on pins, 18 000 lbs. per square inch.

Bearing on rivets. Enclosed bearings, 18 000 lbs. per square inch in the roof and midway floor; 15 000 lbs. per square inch under tracks. Unenclosed bearings, 15 000 lbs. per square inch in roof and midway floor; 12 000 lbs. per square inch under tracks. On field rivets, the above strains were decreased 25 per cent.

The workmanship was required to be similar to that called for in the usual bridge specification.

The work was accurately punched and not reamed.

Copies of all shipping invoices were forwarded to the engineer of the Terminal Company, and the actual scale weights at the shop were checked by calculated weights by the Terminal's Company's engineer. On the total of about 20 000 000 lbs. of steel, these weights agreed within about $\frac{1}{4}$ of 1 per cent. Payments were made on the scale weights, as made at the shop. Monthly payments were made on the material received and erected, and on material delivered on cars in the storage yard at Boston, when consigned to the Terminal Company and not to the contractor.

Train-Shed Covering.

The main roof and side covering is a 2-in. tongued and grooved hard pine sheathing, in 8-in. widths, nailed with iron wire-nails to strips bolted to the jack-rafters. This sheathing, upon the main sweep of the roof and on the tops of the monitors of the midway roof, is covered with "Warren's" anchor brand composition roofing, made up as follows:

Two thicknesses of double roofing felt, manila side down; two thicknesses of natural asphalt roofing felt, each sheet mopped under its full width and upon the top surface with natural asphalt roofing cement, upon which is laid a sufficient body of well-screened dry white Long Island beach gravel.

The tops of all monitors on the train-shed roof and the main portion of the midway and connecting roofs, as well as all side and end sheathing, are covered with 16-oz. copper, as are also all of the exterior main parts of the window-frames in the ends and sides of the train shed and the sides of the monitors. All flashing, cornices, gutters and down-spout connections are of copper.

The train shed and midway are lighted through asbestos-covered wire-glass, bedded in putty, fastened in with wooden strips in wooden sash, fastened with brass screws to wooden frames bolted to the train-shed steel. All the glass is set vertically, and permanent foot-walks have been provided, so that it will be possible to reach each pane of glass in the shed at any time with brushes and water to keep it reasonably clean. The glass is $\frac{3}{8}$-in. thick.

It is not intended that it shall be necessary to shovel any snow from the main roof. All the down-spouts, which are 8 ins. in diameter and generally 60 ft. apart, are covered with jackets, and steam pipes have been run between the spouts and the jackets to keep them from freezing in the coldest weather.

The ventilators are made of timber, are of ordinary louver pattern, and are distributed quite uniformly throughout the monitors. Ventilation over the midway is obtained by opening some of the windows in the monitors. All the woodwork is covered with three coats of white lead and oil paint, the finishing color being on the outside a dark green or copper color, and on the inside a medium drab.

It is believed that this is the first instance where foot-walks have been provided on such an extensive scale, practically to every window, in any train shed, and where the lighting is done exclusively through vertical windows. The result has been very satisfactory.

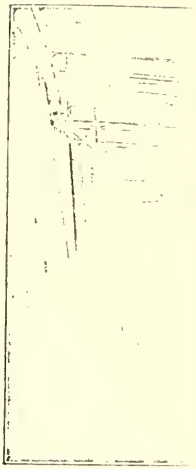


FIG. 1.

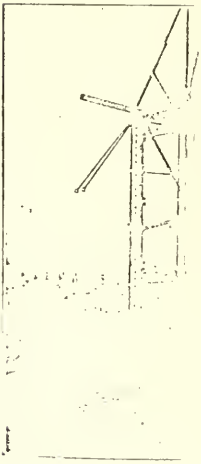


FIG. 2.

HEAD HOUSE.

The main entrance to the station is at the intersection of Federal Street, Summer Street and Atlantic Avenue, and it is here that the main architectural features of the station are found.

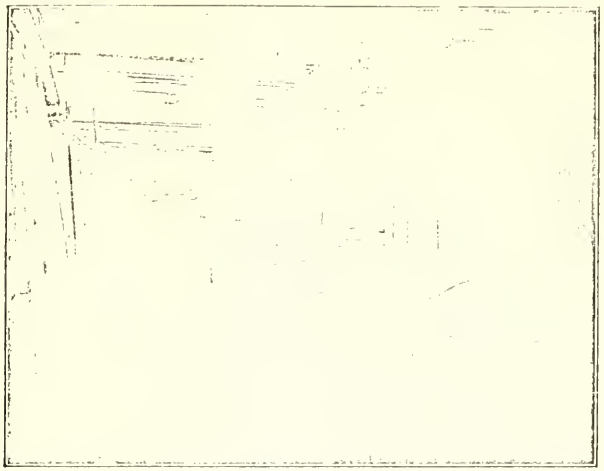


FIG. 1.—NEW CITY SEWER, STRAPPED PORTION.

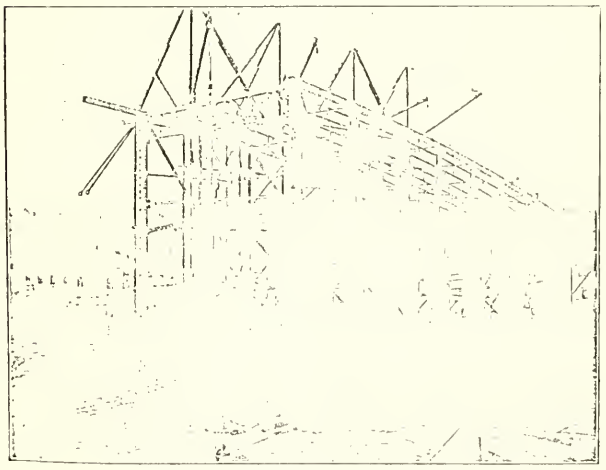


FIG. 2.—PROGRESS OF ERECTION OF TRAIN SHED.

The building extends from this entrance, 792 ft. along Atlantic Avenue (formerly Cove Street), and along Summer Street 672 ft.; then turning the corner of Dorchester Avenue, it extends 725 ft. further, making the total street frontage of the head house 2 189 ft. Two stories, for this entire length, are given up to station purposes, and the three upper floors of the five-story building are used for office purposes by the operating railroad companies.

The five-story building, or main office building (in the middle of which is the main entrance), is 875 ft. long, of which 228 ft., or the portion at the main entrance, is curved.

Of the curved portion, two stories form a massive base, in which are the three large arches forming the entrance. The upper three stories are treated as a colonnade. There are sixteen of these columns, 4½ ft. in diameter, and 42 ft. high. These columns support an entablature and parapet, with a projecting pediment over the center. Above this pediment is a clock, with a dial 12 ft. in diameter, in an elaborate granite setting. Over the clock is a large granite eagle, with wings partly spread, stooping as if just ready for flight. This eagle is about 8 ft. high, and the same breadth over the wings.

In front of the building, opposite the center of the main entrance, there has been erected an ornamented polished granite column, upon a heavy polished granite base, to carry five large electric lights. This column is about 40 ft. high.

The curved portion of the building is of cut granite, and nearly all the remaining front of quarry-faced granite, laid in courses. Upon the front of each wing of the five-story building there are large panels of buff brick, which relieve the severe appearance of the granite.

There is a secondary entrance to the station from Atlantic Avenue, also an exit from the subway. The remainder of the front on this avenue is devoted to the outward baggage-room, the doorways being protected by an iron and glass awning, extending out sufficiently to cover all baggage in transit from the wagons to the building.

On the Summer Street side there is a series of large arched windows to give light to the waiting room; beyond these is the main exit, a wide passageway leading directly from the midway to the street and passing over the subway inclines by a bridge. These inclined subway exits are below the ground-floor level, and lead up to the street from the subway platforms, avoiding the use of steps.

The carriage concourse is at the corner of Dorchester Avenue and Summer Street. Opposite the train shed, on the Dorchester Avenue side, is the inward baggage room, about 550 ft. long. Here, again, the doorways [illegible] beams are protected by an awning. The awning along Summer Street is about 40 ft. wide, and protects the subway exits as well as the sidewalk.

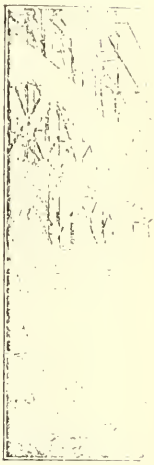
The sidewalks all around the station are lighted by the Terminal Company from their own electric plant.

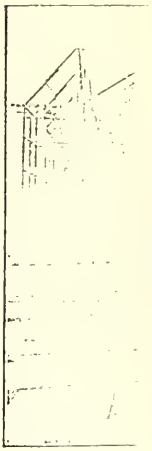
The main entrance is a thoroughfare 90 ft. wide, lined on each side with polished Stony Creek granite. Within the entrance are four large polished granite columns, about 3½ ft. in diameter, which support the offices above. In the polished side walls are cut the date of the erection, the names of the constituent railroad companies, and the trustees of the terminal company, also the names of the mayor, engineers, architects and builder. The ceiling is of white enameled brick, and the iron beams are enclosed in white marble.

Opening from the midway, on the right, are the parcel room, entrance to elevator and stairway hall leading to the offices, and the outward baggage room. On the left are toilet rooms, telegraph, telephone, ticket offices and information bureau, separated by openings to the waiting room. The ticket office has eleven windows opening on the midway and sixteen on the waiting-room side.

The waiting room is 225 ft. long, 65 ft. wide, and 28½ ft. high, and out of the line of traffic. The floor is marble mosaic, laid with a large and handsome pattern. The sides have a dado of enameled brick, set on a polished granite base, and above this the walls are of plaster—tinted. There are three polished granite doorways, and two Verd-antique drinking fountains. The room is lighted during the day time from windows on Summer Street and also from windows above the midway roof (which was kept low partially for this purpose), and by night from 1 200 incandescent lamps distributed along the side walls and in the deep modeled stucco coffered ceiling, giving a beautiful, unobtrusive and well-diffused light. Along one side are arranged great oak settees, placed to form alcoves. On the middle axis of the room are two large ornamental kiosks for the sale of confectionery and flowers.

The women's waiting room is entered from one corner of the main waiting room. This room is 34 by 44 ft., and is furnished with rock-





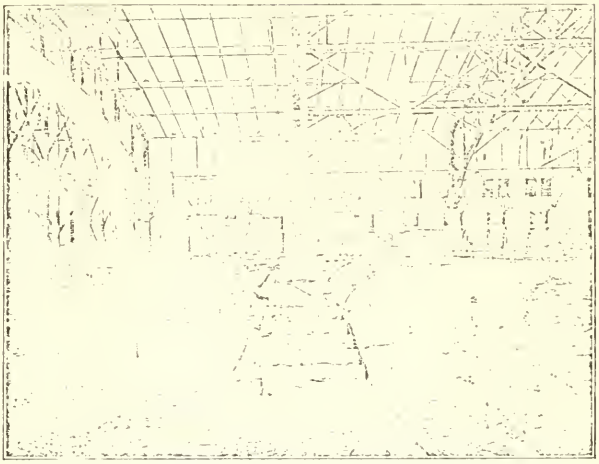


FIG. 1.—PIER AND TRAIN-SHED COLUMNS.

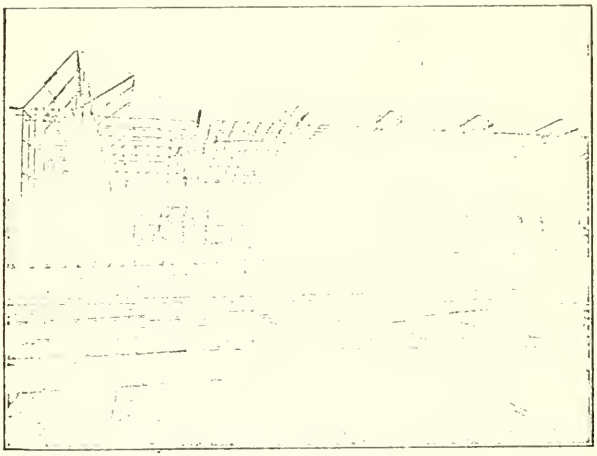


FIG. 2.—PROGRESS OF ERECTION OF TRAIN SHED.

ing chairs, lounges, tables, cribs and cradles. Adjoining are ample free and pay lavatories.

At the easterly end of the waiting room is the main exit and stairway to the subway, also an elevator to the offices and subway. Beyond the exit is the lunch room, 67 by 73 ft., with marble mosaic floors and side walls similar to the waiting room. Here are about 200 stools at the lunch counters, which latter are made with Tennessee marble face and mahogany tops. Next comes the serving room, also the elevator and stairway to three large dining rooms on the second floor. The kitchen and other serving rooms are also on the second floor. Near this last elevator, on a mezzanine floor, is an emergency room, with proper instruments and attendants for giving first aid to the sick or injured. Following along the midway are the station master's office, barber shop, shoe-polishing room, public lavatory, smoking room and carriage and transfer office, and at the extreme end of the midway is a passage to the inward baggage room.

In the midway are arranged five large booths, for the sale of newspapers, fruit, tobacco, drinkables, and for the rendezvous of the baggage porters.

Below the main floor are rooms for baggage storage, emigrants and restaurant purposes.

The second floor is occupied by the administration offices of the Terminal Company, and the trainmen.

The third floor is occupied by the main offices of The Boston and Albany Railroad Company, and the fourth and fifth floors by the local offices of The New York, New Haven and Hartford Railroad Company.

There are nearly 100 clocks throughout the buildings, all self-winding, and governed by electric connections from the master clock in the station master's office. There is also installed a system of watchman's magneto-alarm clocks, a magneto-box being placed near each treasurer's vault, as well as at other suitable points.

All the departments are supplied with ample fire-proof vault accommodation, the largest being 44 x 24 ft., and used to hold engineers' plans. Fire-alarm boxes and push-buttons are arranged at suitable points and connected with the city's fire-alarm system, and movable hose reels are also installed at various places about the premises.

Norcross Brothers, of Worcester, Mass. (O. W. Norcross, proprietor), were the contractors for the entire head house, including the foundations, the foundations for the train shed, the train shed and connecting roof coverings; also for the express and power buildings, and nearly all the subway foundations and masonry.

Plumbing.

Throughout the terminal buildings there are about 45 toilet rooms, fitted up with first-class apparatus, generally known under the trade name of "Sanitas" fixtures. All the water-closets in the free public lavatory rooms are automatically flushed by the seat movement. The closets in the pay and office lavatories have a chain pull. There are upwards of 200 water-closets. The urinals are automatically flushed at adjustable intervals. Nearly all fixtures are connected with the ventilating fans in the attics.

In all the principal toilet rooms there are porcelain slop sinks, fitted with hot and cold water, as well as an ample supply of wash bowls and mirrors. For the train men there are several shower baths.

Each toilet room has an asphalt floor, and a pail and broom closet.

The restaurant plumbing is equipped with large grease traps, and there is a thoroughly ventilated swill room, where the swill buckets, after being emptied, can be cleansed with hot water upon the floor. This room being below the street sewer level, the wash water is lifted by means of a "Shone pneumatic ejector."

Water Supply.

The water used throughout the terminal is taken from the city water mains. For the fire supply, from the high-service pipes, it enters the building at five different places, and a complete outfit of standpipes and hose is established from basement to attic. For the general supply, the water is taken from the high-service mains for the five-story building and from the low-service mains for the other buildings. A 12-in. main is laid clear across the yard near the end of the train shed, from which a supply is obtained for locomotives, through stand pipes, and through which a circulation is maintained, so that it is practically impossible to deprive the power house of water. The general supply enters the premises at fifteen different

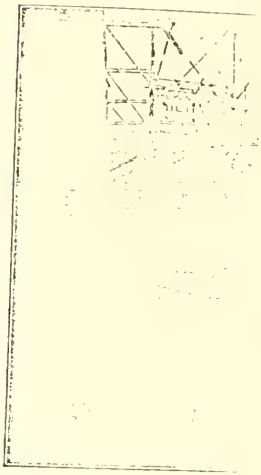


Fig. 1.—Progress.

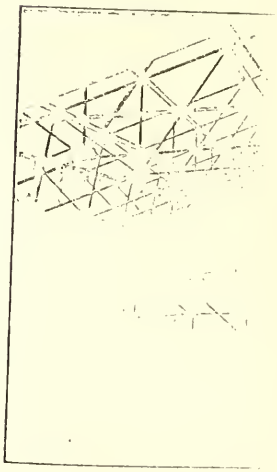


Fig. 2.—View Through.

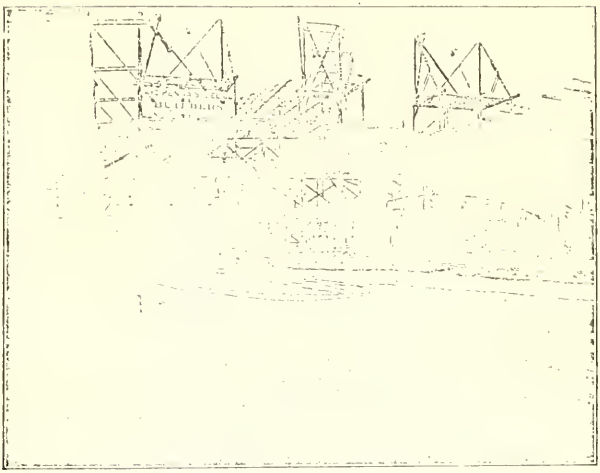


FIG. 1.—PROGRESS OF ERECTION OF TRAIN SHED.

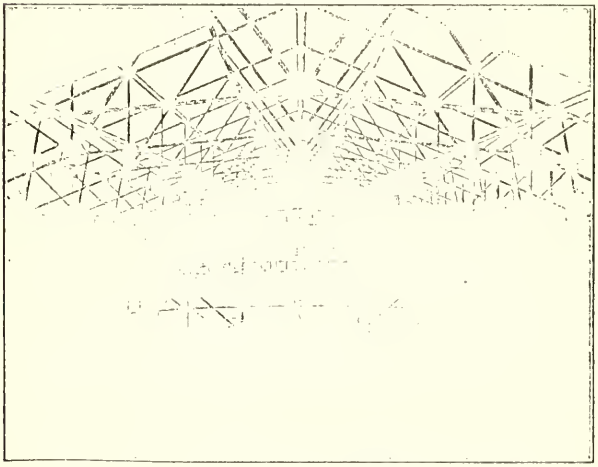


FIG 2.—VIEW THROUGH MAIN MONITOR OF TRAIN SHED.

places, and at each point the consumption is determined weekly by meters set for the purpose, and any excessive use quickly located and corrected. There are also several other meters to measure water supplied to tenants in the express buildings and restaurant.

Present indications show a probable annual expense for water in the neighborhood of $9 000. No actual trials were made to obtain water from driven or artesian wells, but, judging from the experience of others not far away, it was not expected that it could be thus obtained without being slightly brackish.

Interlocking.

The system of interlocking adopted at the South Terminal Station is what is known as the Westinghouse electro-pneumatic.

Previous to the selection of this system, plans were drawn to show the adaptability of both the mechanical and the electro-pneumatic systems. Owing to the demand at this station for a large and elaborate track layout, to serve the 737 trains (total of inward and outward) which would use it immediately upon its completion, and the fact that this number of trains would create many more times the number of train movements than 737, it required a larger interlocking plant than had been heretofore operated anywhere from one tower. When the plans were drawn for a mechanical plant, it was found that a very large building was required, and that a very large area of valuable land would be taken for the lead-out piping, the width required, near the tower, in each direction, being about 45 ft. No suitable way could be found to place this piping in a vertical position. It was also plain that a very much larger number of men would be required to operate the mechanical plant than the electro-pneumatic, and that it would be difficult to make such rigid foundations for the pipe lines on the new fill over the old docks as they require, without waiting a great many months for the banks to settle. It also appeared that, owing to the very magnitude of the plant, which called for unusual treatment, it would cost as much, or perhaps more, to establish the mechanical as the pneumatic. So that even with the remote possibility of electric currents, required in the pneumatic plant, becoming troublesome when electric motive power should be adopted, there seemed to be no other reasonable alternative than to select the electro-pneumatic system.

In the tracks embraced in the control of No. 1 tower are switch and frog points equivalent to 238 ordinary switches. Eleven trains may move to or from the train shed at one time, to control which there are 148 semaphore signals.

In giving a description of the interlocking machine and the electro-pneumatic valves, it will be necessary to quote partially from descriptions by those who are more thoroughly posted in all the details than the writer. Each pair of switch points and each semaphore are attached to the piston of a pneumatic cylinder, which is secured to the switch or signal support. The admission and discharge of air to or from the cylinders is controlled by valves, which in their turn are shifted by electro-magnets, governed by the interlocking machine in which are horizontal rotating shafts, moved by small levers through an arc of 60°, with electric contacts thereon, suited to give the required condition to the magnets at the valves, and thereby produce the proper movement of the switch or signal.

The rotating shafts are arranged to move bars above them, and at right angles to them, which interlock with one another by a system of cross locks. These bars extend from end to end of the machine. The ends of these shafts are engaged by the armatures of electro-magnets, which are so governed, by the switches and signals operated, that the levers and the apparatus operated by them must agree in position before a prescribed route may be given.

A working model is attached to the interlocking machine, showing all the switches moved by the interlocking, corresponding to the movements in the yard, and this model gives a correct representation of the track connections.

There are nine steel-truss signal bridges in the yard, and the signals generally are placed upon them. The semaphore posts are hollow iron columns, with the operating connections inside, and are set, as far as possible, over the center of the track to which they apply. The blades and lights adopted are in accordance with the system of the New York, New Haven and Hartford Railroad, which company operates more than two-thirds of the trains entering the station. The blades extend to the right from the pole. Forked blades are used, to some extent, to indicate that a route clear through the system has been arranged, and at the last signal before entering the train shed to indicate whether or not cars are standing upon the

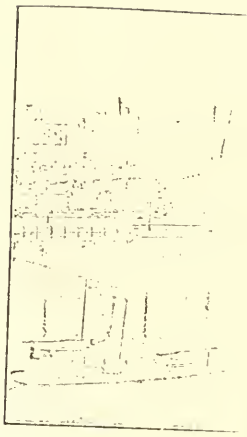


FIG. 1.—S

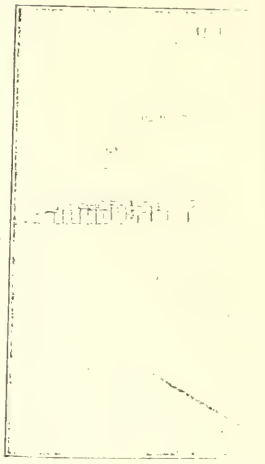


FIG. 2.

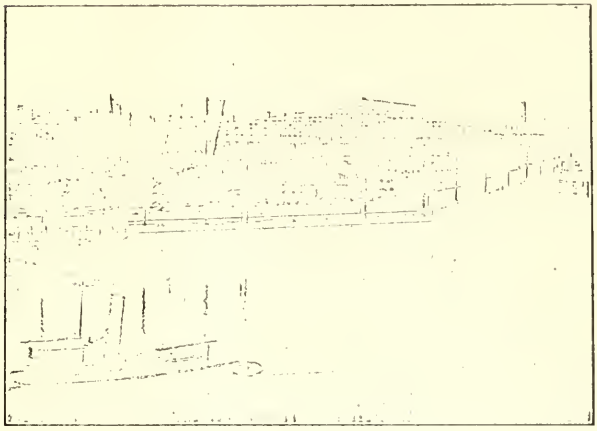


FIG. 1.—SOUTH END OF TRAIN SHED.

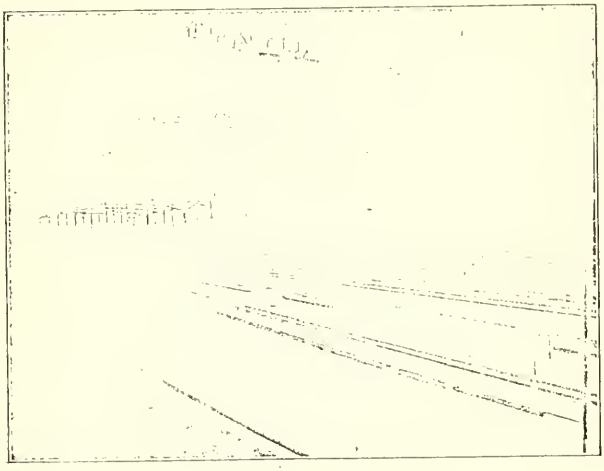


FIG. 2.—INTERIOR OF TRAIN SHED.

track in question inside the shed. Red is used as a stop, green as an all right, and yellow as a caution signal color.

The air cylinders used to move the signal arms are single-acting, the arm being held in a stop position or brought back to a stop position by a counter-weight, and therefore require but one valve.

The air cylinders used to move the switches are double acting, and, therefore, require two pin-valves (one for each end of the main cylinder), controlling auxiliary cylinders, which shift a D-valve, capable of more readily controlling the pressure to and from the switch cylinders. The D-valve cannot act unless a plunger which prevents its movement is first withdrawn. This is effected by a third magnetic valve, and auxiliary cylinder, and the three magnetic valves are controlled by three separate wires extending from them to contacts of the interlocking machine. The D-valve is used on account of the large volume of air required to be admitted in a short space of time.

The first part of the stroke of the main piston moves the detector bar, the middle part moves the switch, and the latter part locks it in position; consequently, if a detector bar cannot rise, owing to being held down by the wheels of a train, the switch cannot be thrown. There are in the power-house two air compressors, which furnish the air power. They are 14 x 18-in. Ingersoll-Sargeant, class "A," compressors. One is held in reserve as a relay to the other. Each compressor discharges the air into receiving tanks, from which it is conducted to a third receiver. The air mains leading from the receiver are duplicated, so that failure in one line of piping will not prevent an immediate operation of the switches and signals through another line. The air passes through cooling devices, consisting of manifold pipes, which precipitate all moisture, and at each switch enters a cast-iron receiver. From this reservoir there is an armored hose connection to the switch valve. This elastic connection prevents injury to the connections, due to vibration and settlement.

There are also provided indicators from the train house to the tower for proper communication, and the towers are equipped with telephone connection to all necessary points.

Tower No. 2 controls switches and signals on the suburban tracks, and Tower No. 3 governs train movements at the yard limits too remote to be controlled from Tower No. 1.

These towers and the other main-yard buildings are of brick, with

ELECTRO

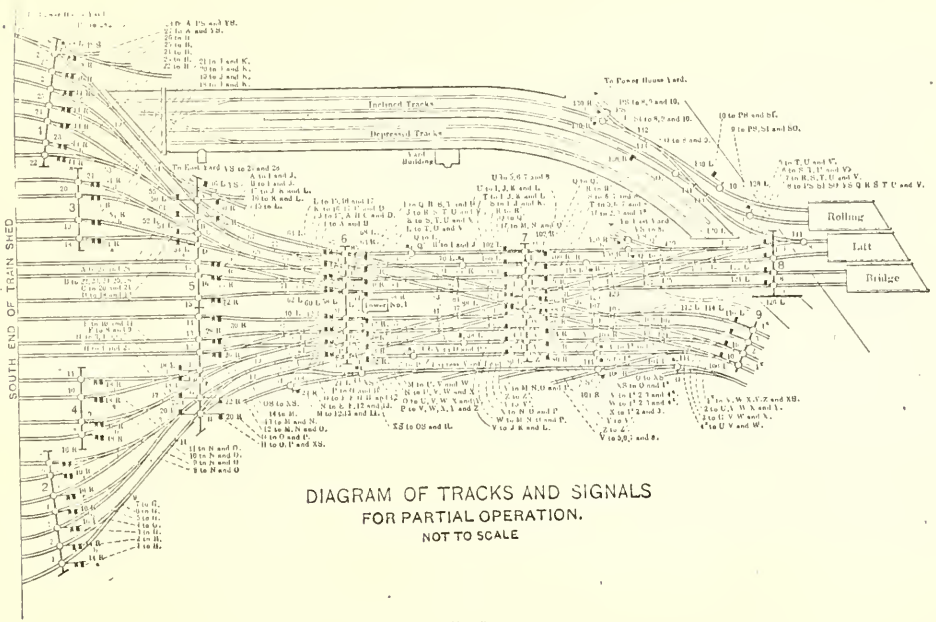


FIG. 9.

ELECTRO-PNEUMATIC SWITCH AND LOCK MOVEMENT,
APPLIED TO A SIMPLE SWITCH.

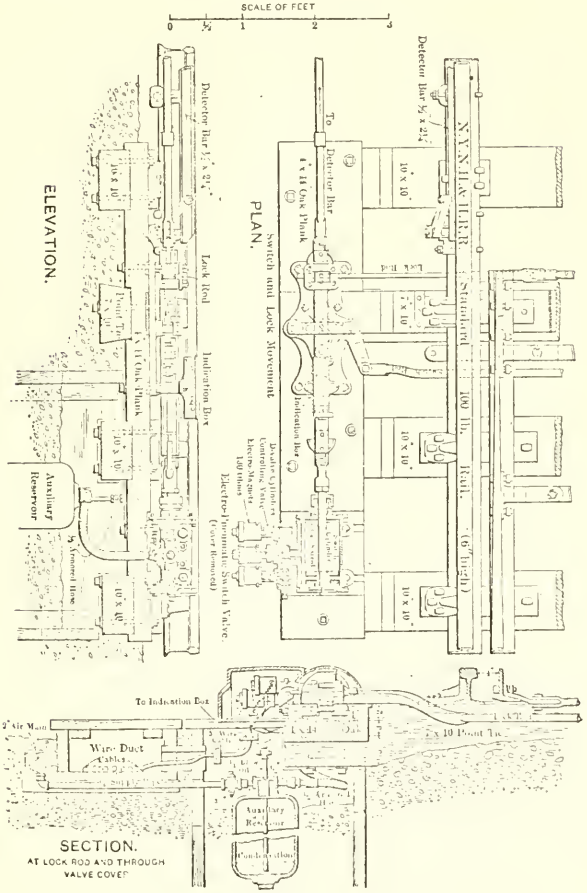


FIG. 10.

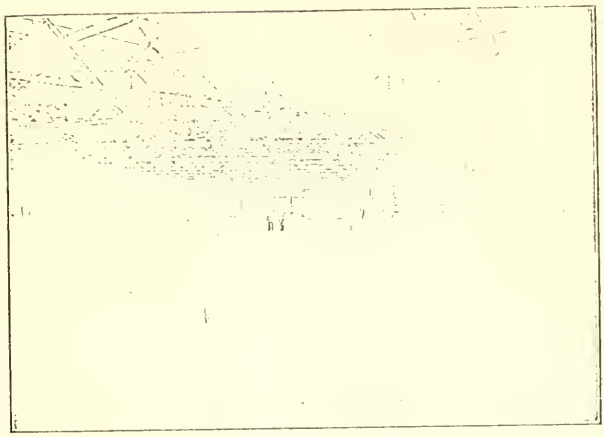


FIG. 1.—THE MIDWAY, LOOKING EAST.

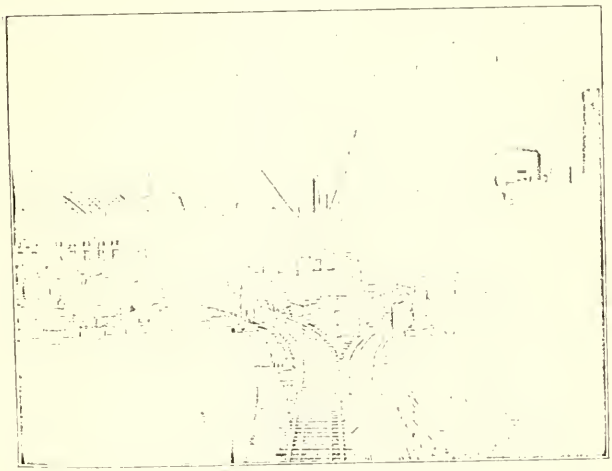


FIG. 2.—SERVICE TRACK CONNECTIONS WITH N. E. R. R.

slate roofs, and contain toilet fixtures for the accommodation of the employees.

Signal Lights.

Oil lamps are used for signal lights, excepting on one signal bridge, where experiments are being made with electric lights. These experiments have not progressed far enough to prove conclusively the superiority of electricity, but give evidence of doing so. The trial lights consist of two 8-candle-power lamps in each lantern, so that in case of failure of one, the other may do sufficient duty. They are very clear, and penetrate fog better than the oil lamps.

If the details can be arranged to give satisfaction in all kinds of weather, they will undoubtedly be adopted.

Data are also being collected to determine the comparative cost.

Track Grades.

The tracks in the train shed are level. At the throat of the interlocking they are 2 ft. lower than in the shed, to ease the grade on the curved approach, which is about 40 ft. to the mile (upon 8° curves), and to facilitate reasonable connections with the express-yard tracks, which of necessity lie at a grade 6 ft. lower than the main tracks.

The grade of the tracks on the drawbridge is practically the same as in the train shed.

The steepest grade in the express yard is about 1½ per cent.

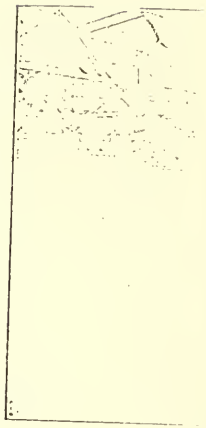
The loop tracks are level. The grade upon the inclines leading to the loop tracks does not exceed 2½ per cent.

In the train shed the tracks are level with the platforms; in the mail and express yard the tracks are about 4½ ft. below the level of the platforms, the latter being substantially on a level with the floor of the cars.

Express Buildings, Team and Car Yards.

The express buildings are 50 ft. wide and two stories high. They are owned by the Terminal Company and leased to the express companies. They are similar in style and appearance to the power-plant buildings.

One portion of the express tracks is laid parallel with the building,



Fig

Fig. 2.—Sle

as requested by the express company occupying that part of the building. The other portions of the tracks are laid as spurs, at an angle to the building, with intervening platforms. This arrangement was necessary to get the room required for cars.

The team side of the building has a covered platform nearly its entire length, and the yard is paved with granite blocks. The second floor is used for offices by the Adams Express Company, and store rooms for the New York, New Haven and Hartford Railroad Company. A portion is unused at present.

Heating and Lighting for Express and Yard Buildings.

The express buildings are heated by hot water, directly through radiators in the various rooms. It is not intended that the freight rooms and store rooms shall be kept much above freezing in the winter, but the offices are thoroughly warmed.

The piping system is entirely separate from the head-house system after leaving the power house, and was installed under a separate contract. The fire-risers through the freight rooms, in this building, as well as those through the baggage rooms in the head house, are boxed and protected from the frost. The platforms and freight rooms are lighted by arc lights, and the office rooms by incandescent lights. Two of the five electric truck lifts go to the store rooms in the second story, and these two are arranged with safety clutching devices.

The yard buildings are heated by steam and lighted by electricity.

Power Plant Buildings and Pipe Subways.

The power-plant buildings are substantial hard-burned brick buildings, with granite trimmings and flat gravel roofs upon steel trusses. They are 40 ft. wide and two stories high, with an aggregate length of 580 ft.

The pipe subways leading from the power plant to the head house and express buildings are 6 ft. wide and 5 ft. high, and are built entirely of Portland-cement concrete, as shown in Fig. 4. They carry the pipe lines on one side and the electric cables on the other, and are well lighted. There is no portion of the wiring or piping underground which is not accessible at a moment's notice, and one may travel these subways in a "Sunday Suit" without harm to it.

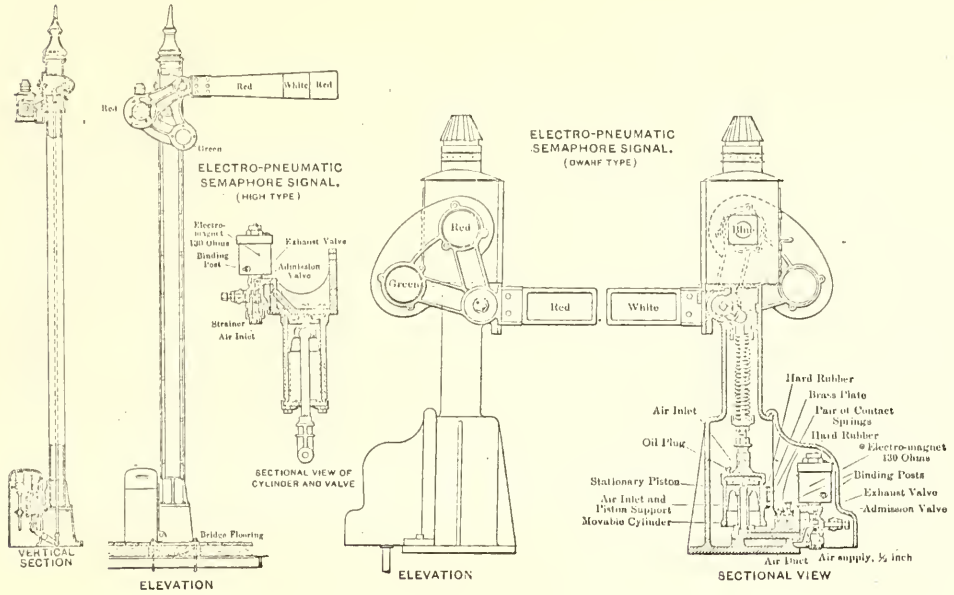

VERTICAL SECTION
Red
White
Red
Green
ELECTRO-PNEUMATIC SEMAPHORE SIGNAL. (HIGH TYPE)
Electro-magnet 130 Ohms
Exhaust Valve
Binding Post
Admission Valve
Strainer
Air Inlet
SECTIONAL VIEW OF CYLINDER AND VALVE
Bridge Flooring
ELEVATION
ELECTRO-PNEUMATIC SEMAPHORE SIGNAL. (DWARF TYPE)
Red
Green
Red
White
ELEVATION
Hard Rubber
Brass Plate
Pair of Contact Springs
Hard Rubber
Air Inlet
Oil Plug
Electro-magnet 130 Ohms
Stationary Piston
Binding Posts
Air Inlet and Piston Support
Exhaust Valve
Movable Cylinder
Admission Valve
Air Duct
Air supply, ½ inch
SECTIONAL VIEW

Fig. 11.

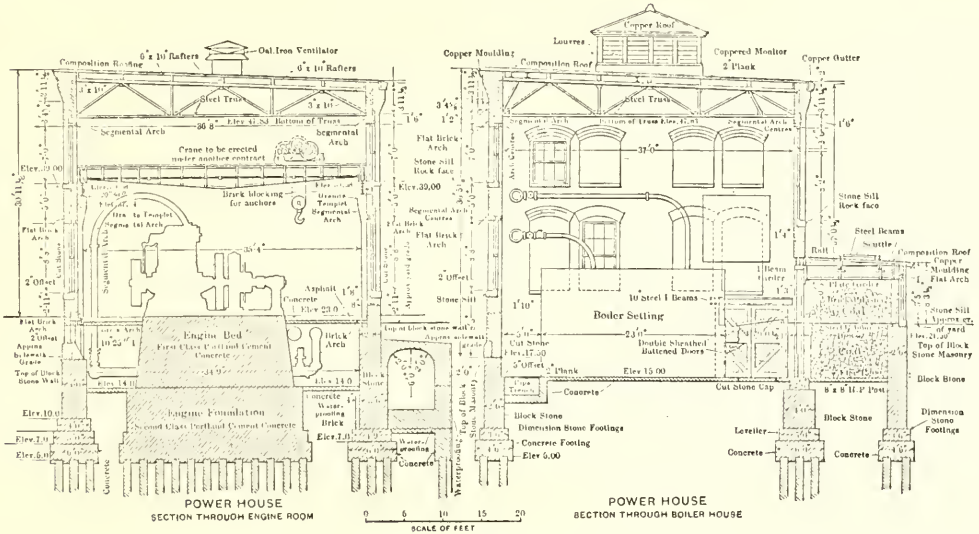
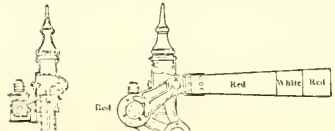
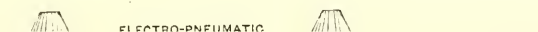

POWER HOUSE
SECTION THROUGH ENGINE ROOM
POWER HOUSE
SECTION THROUGH BOILER HOUSE
SCALE OF FEET
Boiler Setting
Engine Bed
Engine Foundation
Steel Trusses
Segmental Arch
Flat Brick Arch
Stone Sill
Rock face
Concrete
Block Stone
Dimension Stone Footings
Concrete Footing
Copper Roof
Louvres
Copper Moulding
Composition Roof
Coppered Monitor
Copper Gutter
Steel Beams
Stone Sill
Top of Block Stone Masonry
Cut Stone Cap
Double Sheathed Battened Doors
Leveller

Fig. 12.


Red
White
Red
Red


ELECTRO-PNEUMATIC

Power House Equipment.

The buildings which contain this equipment are upon the Dorchester Avenue side of the yard, and in order that they might interfere as little as possible with room for tracks, they have been built tandem fashion; the ice plant nearest the head house, compressor and electrical generating plant next, and boiler house last. These buildings contain ice-making and refrigerating machinery, ice storage room, air compressors to make power for air brakes and the switches and signals, four Westinghouse direct-current generators, to make electric current for lighting, elevators and motors (with room for two more), a central heating plant, ten horizontal return-tubular boilers 72 ins. in diameter and 18 ft. long, an economizer, mechanical stokers, mechanical draught fans and engines, feed pumps, compressors and minor appurtenances.

The apparatus and the size of the units have been selected with special regard to the great variation in load required at different times of the day and year. There is, of course, considerable surplus power beyond absolute necessity, to provide for breakdowns and repairs. The steam piping has been duplicated in such a manner that any accident thereto will not seriously impair the operation of the plant.

The boilers are made from an extra quality of steel, and are designed to carry a working pressure of 150 lbs. per square inch. The shell plates are $\frac{1}{2}$ in. thick, and the heads $\frac{9}{16}$ in. thick, and are well stiffened by angle irons, and braced by five through bolts $1\frac{5}{8}$ ins. in diameter. Each boiler has 130 tubes 3 ins. in diameter, and is equipped with the usual manholes, blow-offs, safety valve, etc. They are suspended from channel beams resting upon wall plates carefully bedded upon the walls of the setting. The boilers are provided with an equipment of Roney mechanical stokers, and provision has been made for a 50% increase in the boiler plant.

The economizers are two in number, one of 520 pipes and one of 240 pipes. The settings are built for 1 040 pipes. The mechanical draught is provided by two slow-speed exhaust fans 14 ft. in diameter and 7 ft. breast, driven by two horizontal engines of sufficient size to drive the fans 100 revolutions per minute. Either or both fans are operated at will, and are designed to produce a draught through the steel stack 11 ft. in diameter, carried a few feet above the roof, equal to a 250-ft. chimney.

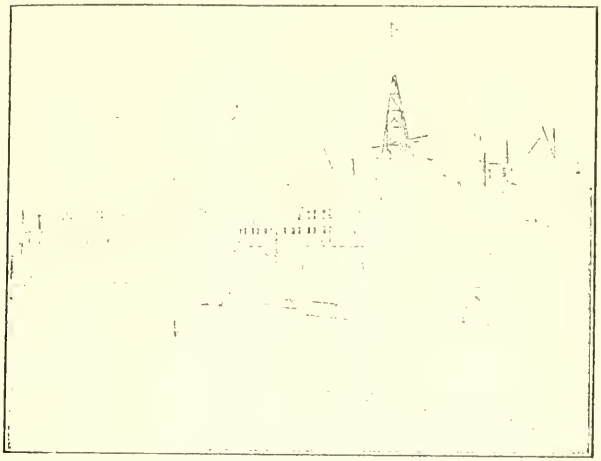


FIG. 1.—VIEW FROM CONGRESS STREET BRIDGE.

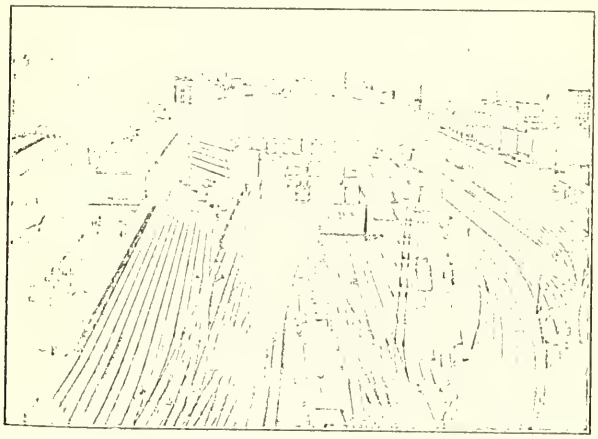


FIG. 2.—VIEW OF YARD AND BUILDINGS ABOUT JUNE 1ST, 1899.

The four Westinghouse, single-valve, compound, automatic engines have cylinders 18 and 30 ins. in diameter, and for 16 ins. stroke of piston, and are rated, when running at their standard speed of 250 revolutions per minute, at 375 I. H.-P.

They are operated non-condensing if the exhaust steam is required for heating purposes, or under a vacuum, as occasion requires. Each engine is directly connected to a 225 K.-W. Westinghouse multipolar engine-type generator, capable of generating current at two potentials, one of 220 volts for power, and one of 110 volts for lighting.

The switchboard is an interesting portion of the installation, but a technical description is out of place in this paper.

A traveling crane of 20 tons capacity spans the engine room.

The other apparatus in the power house is described under the various headings which follow, in their appropriate connection.

The suction pipe from the condenser to salt water in the Fort Point Channel, is laid under Dorchester Avenue in a chamber which permits of entrance to adjust the flanged joints in case of air leaks, leaks being expected on account of settlement of the new street filling. The suction well and inlet chamber are built partially of timber and partially of masonry, and while serving the purpose properly, under the sea wall, have only the merit of being inexpensive.

Electric Lighting.

Before the amount of lighting for the various parts of the station was determined upon, a carefully prepared statement of the lighting of all the large stations in the United States was made, and from this as a guide the lights were arranged. The train-shed platforms, midway, baggage rooms, express platforms, express rooms, entrances and sidewalks are lighted by arc lights of enclosed pattern. In the train shed they are hung from the roof and steadied horizontally by the current wires and guy wires. The switches for the platform lights are located on the midway fence, and each platform may be lighted separately, if desired. The lights on the passenger platforms are 120 ft. apart. The suburban station is lighted by a large number of 5-light clusters of 16-candle-power lamps. These reflect against the enameled brick ceiling.

The waiting room is brilliantly illuminated by lights in the ceiling, and also by a row entirely around the sides.

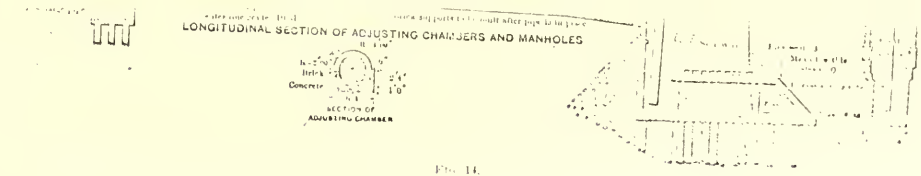
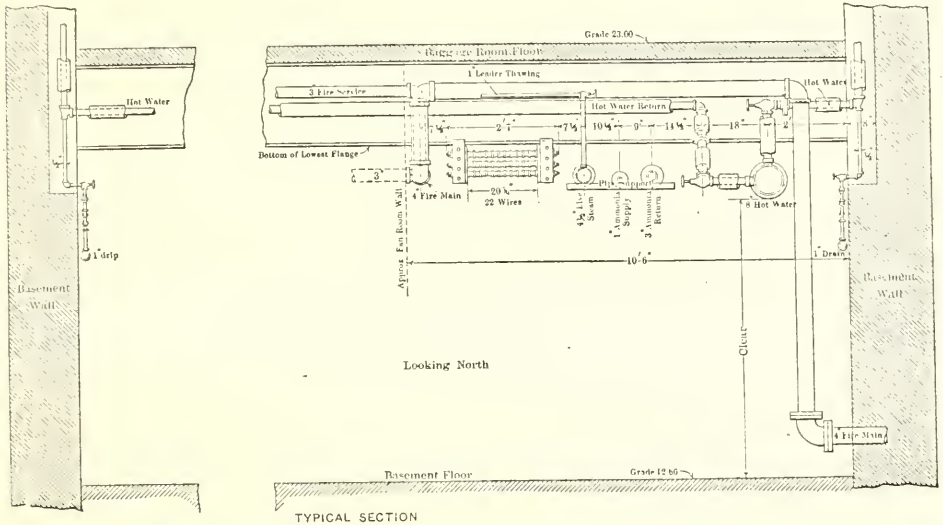


FIG. 14.



TYPICAL SECTION
SHOWING PIPES AND WIRES
IN
DORCHESTER AVE. BASEMENT.

SCALE OF FEET
0 1 2 3 4 5

FIG. 13.

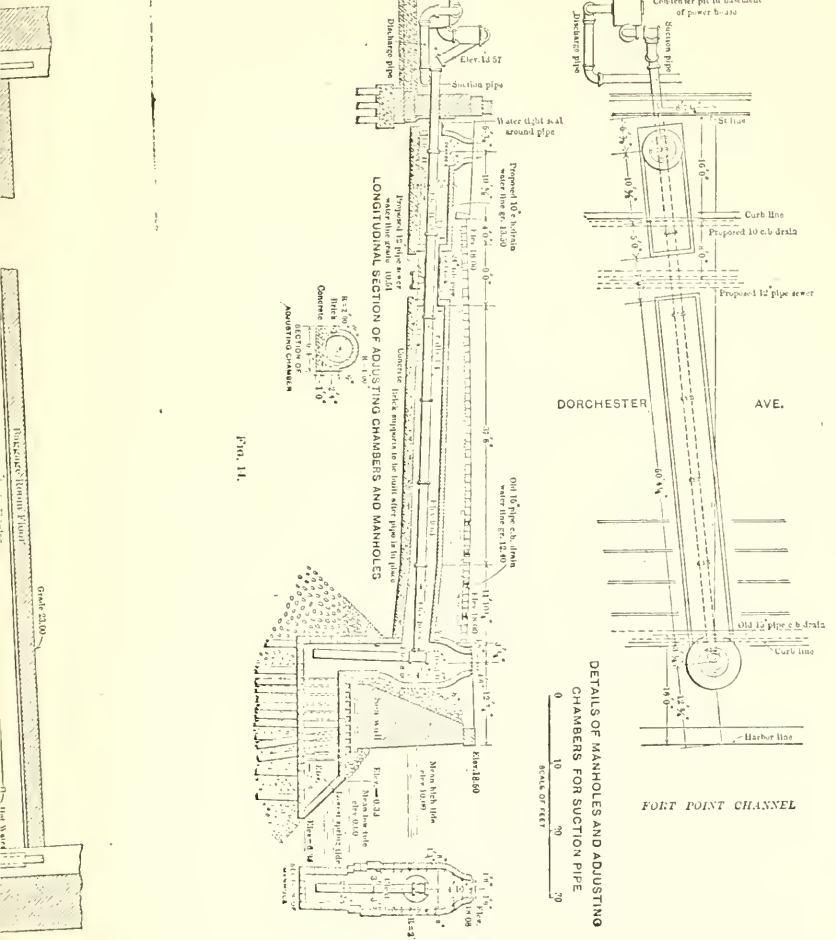
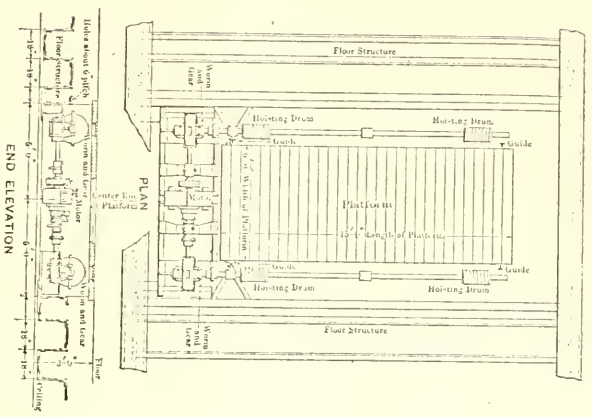

Condenser pit in basement of power house
Discharge pipe
Elev. 14 57
Suction pipe
Water tight seal around pipe
Proposed 10" c.b. drain
water line gr. 13.50
Proposed 15" pipe sewer
water line grade 10.51
LONGITUDINAL SECTION OF ADJUSTING CHAMBERS AND MANHOLES
Concrete
Brick supports to be built after pipe is in place
Old 16" pipe c.b. drain
water line gr. 12.40
Elev. 18.60
Elev. 8.34
Elev. 6.34
Elev. 5.08
Condenser pit in basement of power house
Discharge pipe
Suction pipe
St line
Curb line
Proposed 10 c.b. drain
Proposed 12" pipe sewer
DORCHESTER AVE.
Old 12" pipe c.b. drain
Curb line
Harbor line
DETAILS OF MANHOLES AND ADJUSTING CHAMBERS FOR SUCTION PIPE
0 10 20 30
SCALE OF FEET
FORT POINT CHANNEL

FIG. 14.


END ELEVATION
PLAN
Floor Structure
Hoisting Drum
Guide
Platform
Floor Structure

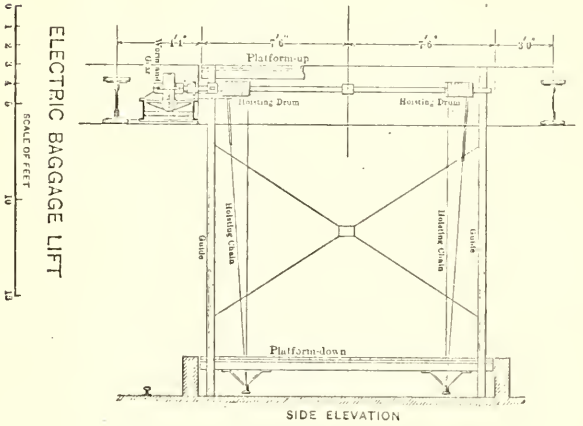
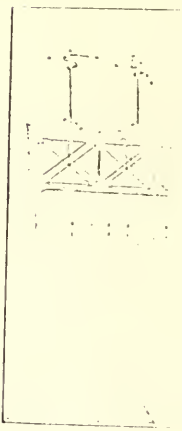

ELECTRIC BAGGAGE LIFT
SCALE OF FEET
Platform-up
Hoisting Drum
Hoisting Chain
Guide
Platform-down
SIDE ELEVATION

FIG. 15.



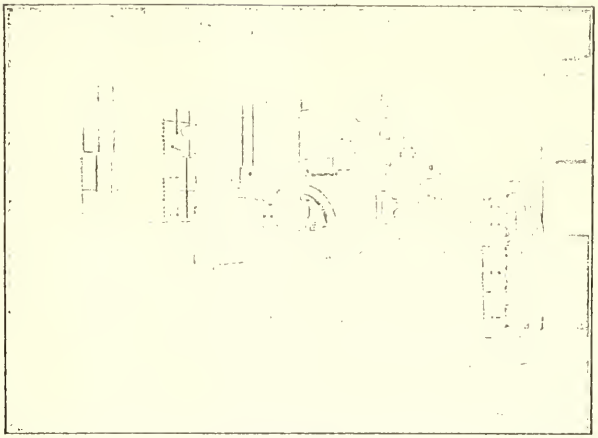


FIG. 1.—AIR COMPRESSORS.

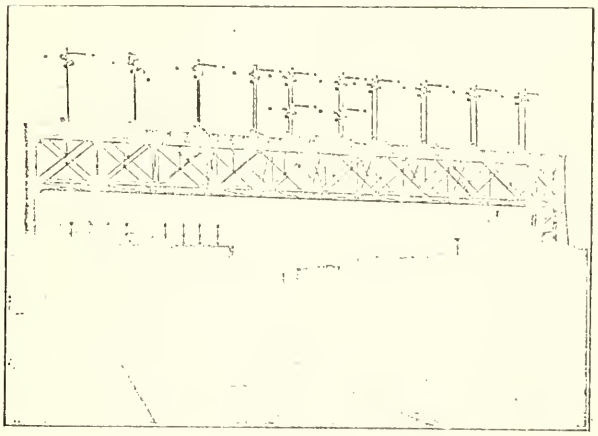


FIG. 2.—SIGNAL BRIDGE NO. 7.

The offices and corridors are lighted throughout with electricity. There are no illuminating-gas pipes in the building.

There are nearly 300 arc and 7 000 incandescent lights.

All the wires are carried in water-tight iron pipe ducts throughout the walls and floors of the building, and are accessible at the various drawing-in, cut-out or junction boxes. There are 18 sets of feeders running from the generator switchboard to the distributing centers about the premises, where there are switches for local control of the lights.

Elevators and Lifts.

All the elevators and baggage and express lifts are run by electricity. There are 5 public elevators and 2 private elevators in the head house, 1 ice lift in the ice plant, 8 baggage and express lifts in the train shed, 4 in the baggage rooms and 5 in the express buildings, making a total of 25. They were all, with the exception of the ice lift, constructed by the Sprague Elevator Company.

The passenger elevators are of the usual pattern, and have no special features.

The baggage and express lifts are of special pattern, and are one of the most interesting features of the mechanical plant. On account of the waterproofing sheet below, which could not be punctured, and the fact that most of these lifts were out of doors, it was not feasible to adopt hydraulic lifts. Further, on account of the impracticability of having any framework more than 3 or 4 ft. above the platforms, between the trains, the baggage platforms being restricted in width so that posts to such framework would be too near the car windows, it was not practicable to have overhead sheaves and ropes. Study, on the part of the contractors, brought out a type of electrical machinery which could be contained in the thickness of the floor. This consists mainly of a revolving shaft on each side of the elevator openings, near the top, which shafts wind up four chains, one near each corner of the lift platform, these shafts being rotated by worm gears, at right angles to them, at one end of the lift, the thrust of one worm gear reacting against the other, and the countershaft being rotated by an electric motor in the floor. This apparatus, being suitable for platforms between trains, and being simple and economical, was adopted for all but two (the two-story lifts in the express buildings), of the seventeen lifts.

The platforms of these lifts are 6 ft. wide and 15 ft. long, and the lifts are designed to carry with perfect safety 3 000 lbs.

The problem of making suitable protection around the opening in the platforms, and safety gates at the ends, was perplexing, but was solved by making a very strong sheet-iron frame for each side, about 3½ ft. high, and placing in each end a swinging gate. This framework cannot be wrecked by a heavy truck, and the gates cannot be struck, when open, by the trucks. The gates are connected, so that when one opens the other opens, and are also arranged by contact latches, so that the lifts cannot be moved if they are open, neither can the gates be opened if the lift is below the platform level. It is necessary to unlatch the gate by hand, which can be done from either end, before the gates are free to open. The baggage-room lifts are not protected by the same style of gate, but the principles are the same. The lifts are operated by foot-pushes at both ends of the platform, so that a man can work the lifts at whichever end he may be. A push on one button raises the lift, and on another button lowers the lift. They are all supplied with call bells and automatic gates at the lower level.

It was necessary to construct the platform over the motors, so that moisture could not find its way to them, and at the same time have the platforms removable, so that the motors and machinery could be got at. After a little study this was arranged without difficulty, and these lifts have given excellent satisfaction.

Heating and Ventilating.

The head house and public rooms are heated by a hot-water system. The water is heated in three tubular heaters, two of them connected to obtain heat by the circulation of exhaust steam from the engines, through them, and the third connected in a similar manner for live steam. The hot water is circulated through the tubular heaters and through a loop system of piping around the head house by means of two centrifugal pumps, one a relay to the other, these being located, along with the tubular heaters, in a room in the power house, and called the central heating plant. The main rooms and offices are warmed by hot air, the air being drawn through down-take shafts from the roof, over hot-water stacks, or radiators, in the basement, by large fans, and forced through one duct to each room, so heated, at a temperature of about 70° Fahr., and through another

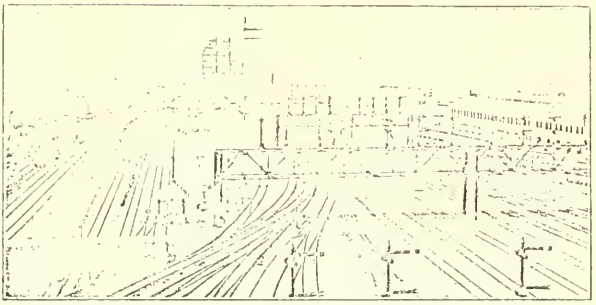


FIG. 1.—EASTERLY PORTION OF YARD AND SUBWAY.

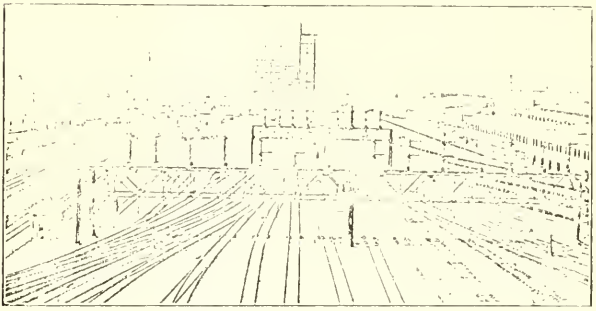


FIG. 2.—MIDDLE PORTION OF YARD.

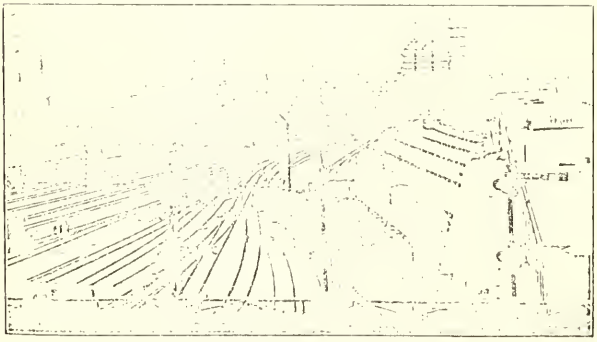


FIG. 3.—WESTERLY PORTION OF YARD.

duct, over a supplementary heating stack, to each room at a much higher temperature. At the register in each room is a mixing damper, so that the inmate can take a full volume of the air at a temperature of about 70°, or at a much higher temperature, at will.

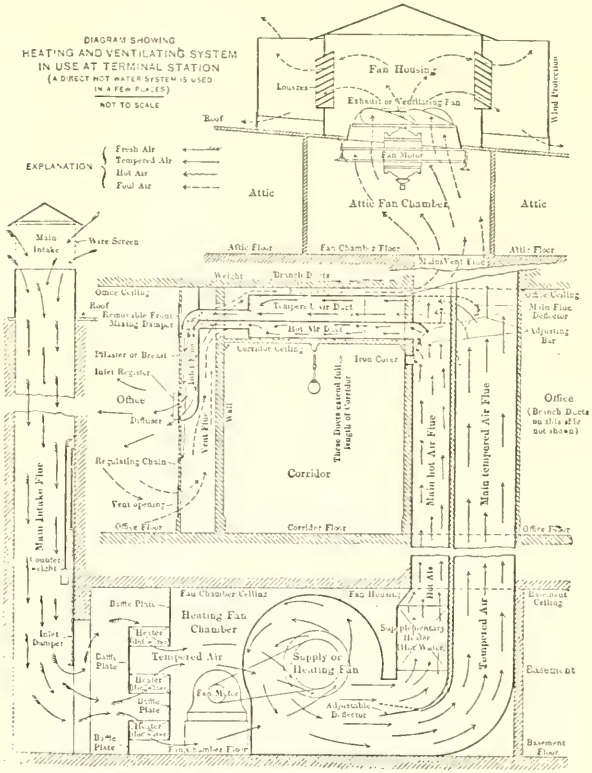


FIG. 16.

The main loop in the system is about five-eighths of a mile long, and large bends have been used freely to take care of expansion and contraction.

There are six fan rooms, of different sizes. In the summer these fans are run to assist in ventilating the offices.

The baggage rooms, some of the corridors, and other much exposed offices are heated by direct hot-water radiators. It is not expected that the baggage rooms will be kept much above freezing in cold weather.

The main ducts of the heating and ventilating system are over the ceiling of the corridors, and all hot-air ducts are thoroughly insulated. The hot-water pipes are all insulated. It is possible to circulate the water at different velocities and at different temperatures, and these are the means used to regulate the heat. There are 12 ventilating fans in the attics which exhaust the air from the office and toilet rooms through special ducts to the outlet chambers on the roof.

All the fans in the heating and ventilating system are driven by electric motors.

All toilet rooms are heated by the direct method, to prevent the accumulation of air pressure in the rooms, which would cause the escape of foul odors through the doors, and are ventilated by special exhaust fans at the roof, fresh air finding its way to these rooms through screened doors.

Ice-Making and Refrigeration.

An ice-making plant, capable of making 20 tons of "Diamond" ice per day, frozen from one side only, upon the plate system, has been installed in the power house. Beneath the freezing tanks an insulated storage vault, large enough to hold 800 tons of ice, has also been built. This ice is used in the cars, restaurant, and some of the offices, and is made from thoroughly filtered water, taken from the city mains, and harvested in large blocks, cut in the freezing tanks by traversing steam cutters, lifted out of the tanks by a traveling pneumatic lift, and lowered to the required level in the storage vault by an electric lift. Later on, it is weighed, cut up into small pieces, and delivered upon demand to the different users.

Two ammonia compressors are provided, one sufficient for the ice-making and refrigeration purposes, and the other for the latter alone.

A refrigerating plant, on the brine system, is installed for the purpose of cooling the storage boxes (of about 4 000 cu. ft. capacity) in the restaurant, and for cooling drinking water, which may be drawn from

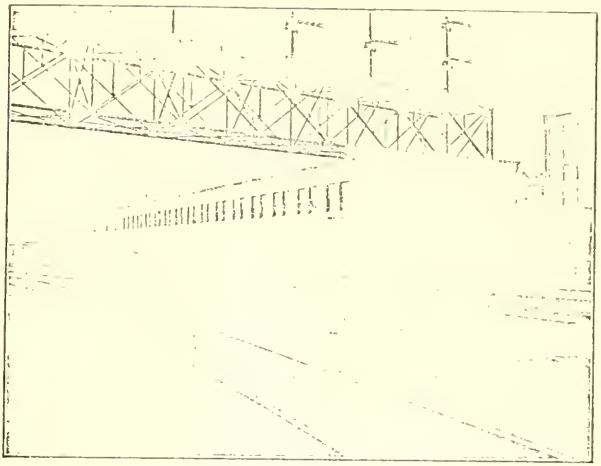


FIG. 1.—TRACK SIDE OF EXPRESS BUILDINGS.

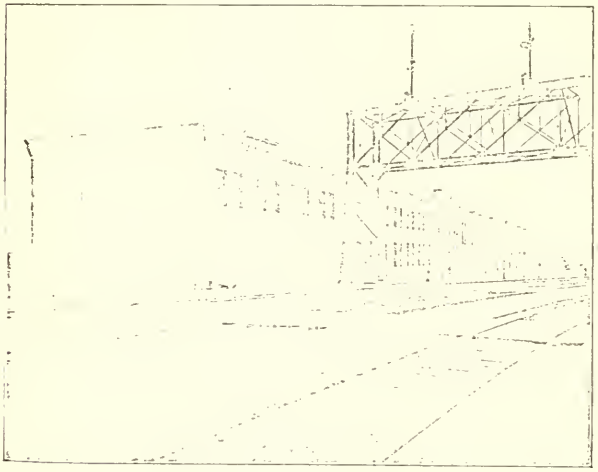


FIG. 2.—POWER HOUSE.

about 30 drinking fountains located in the corridors and public rooms at various places throughout the head house.

Steam and Hot Water for Head House.

A piping system for a supply of live steam and hot water has been installed in the head house for cooking and warming purposes in the kitchen and serving rooms, and for supply to outlets in the pay lavatories, outlets for cleaning purposes, and for the shower baths installed for the train men. All the piping is insulated, and the total number of outlets is about 35.

Car Heating.

At all the stub-track ends in the train shed and throughout the express yard, 47 places in all, provision has been made for furnishing steam heat to the cars. The steam pipe at the ends of the tracks in the train shed is on the loop system, and any break in the main pipe does not interrupt the supply to any great extent. Perhaps the only interesting feature in this provision is the style of metallic universal-joint connection to the car hose, which is what is known as the McLaughlin joint, a recently devised joint of very simple pattern, hardly to be described without detail drawings.

Air Brake Testing.

Two Westinghouse air-brake pumps are installed in the power house to supply air for testing brakes and charging the cars, and this air is delivered at the 47 stub tracks in the train-shed and express yards. A main and several auxiliary reservoir tanks are used to provide storage for excessive draught at times, and provision is made for draining off the condensation water at the various low points in the pipe lines, and at the reservoirs. At the track ends in the train shed the air passes through rubber hose to the car connection. Out of doors the air passes through the McLaughlin metallic universal joints. The latter feature is a new departure for air connections.

This system of compressed-air piping and machinery is kept separate from the compressor plant for switches and signals, so that a failure in the former will not affect the more important work of the latter. There is no physical reason why they could not be arranged as one plant, if so desired.

Fire Protection.

A 4-in. water-pipe connection has been made at five different points with the high-service mains of the city water-works, and fire-riser pipes, 3 ins. in diameter, with hose and nozzles, have been installed all over the premises. Altogether, there are 104 outlets for 2½-in. hose in the main building, and 2 outlets in the interlocking towers for 1½-in. hose, 6 of the former being on the roof of the main building. No outlets for this fire supply or any other hot or cold water supply are located over the main waiting room.

In addition to the above, there have been installed about the head house several auxiliary fire-alarm boxes, connected with the city fire-alarm system, which can be rung from 22 push buttons located in various places. Additional hose, on reels and in boxes, has been provided for emergency. No fire-fighting organization of employees has been made, reliance being placed on the city department, which can be had at immediate notice. One fire, which did no great damage, caused by a blacksmith's forge on the roof, within a few days after the station was opened, was observed in the attic by an employee, and extinguished with water from the established system, without recourse to the city department, thus illustrating the virtue of this private system.

Frost Protection.

The twenty-two 8-in. and the two 12-in. down-spouts from the train-shed and midway roofs are jacketed with non-conducting covering, and the jacket spaces are warmed in freezing weather by coils of 1-in. steam pipe. The jacketed space is 1½ ins. wide, and wire lathing serves as a base for the non-conducting covering. This covering is an asbestos compound, and it is protected by heavy canvas, well painted. The live steam for the coil, which is two runs of 1-in. pipe, forming a loop by connection near the roof, is supplied from a distributing system, having its origin in the car-heating main.

These jackets have served to keep the down-spouts open one winter, and it is hoped that they will prove as valuable in the future. A 2-in. brass pipe to carry live steam has been installed entirely around the midway roof in the gutter, to keep the gutter open. No other steam pipes have been provided for melting snow.

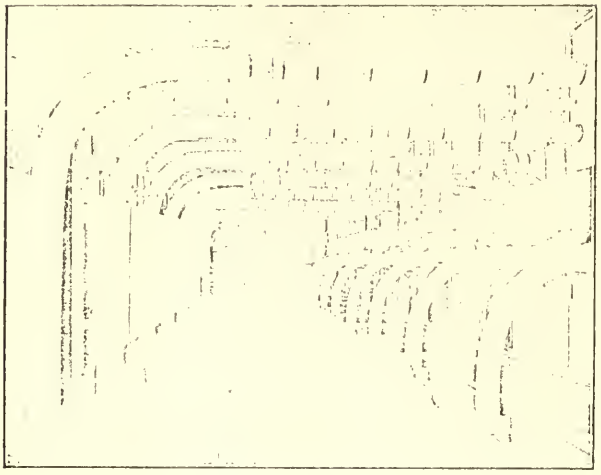


FIG. 1.—PIPING, OVER BOILERS.

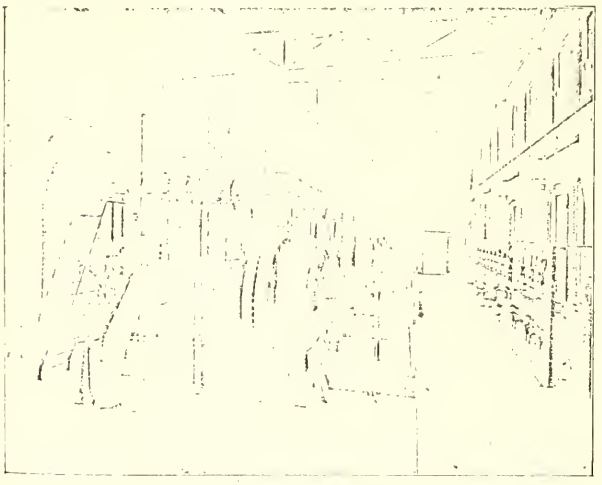


FIG. 2.—INTERIOR OF ENGINE ROOM.

Pumping Plant.

As the entire suburban station is below the level of the ocean, and as part of the track-approaches to it are open to rain and snow, it has been necessary to provide a pumping plant in a sump well, located near the power plant, to take care of storm water and any seepage water which may eventually get through the waterproofing sheet. This plant consists of two electrically driven, vertical-shaft, centrifugal pumps. One has a capacity of 4 000 galls. per minute, and the other 1 000 galls. per minute, against a head of 16 ft. The smaller pump is arranged to work automatically, being governed by a float. The other is started by hand upon an electric alarm signal controlled by a float, giving notice in the power house.

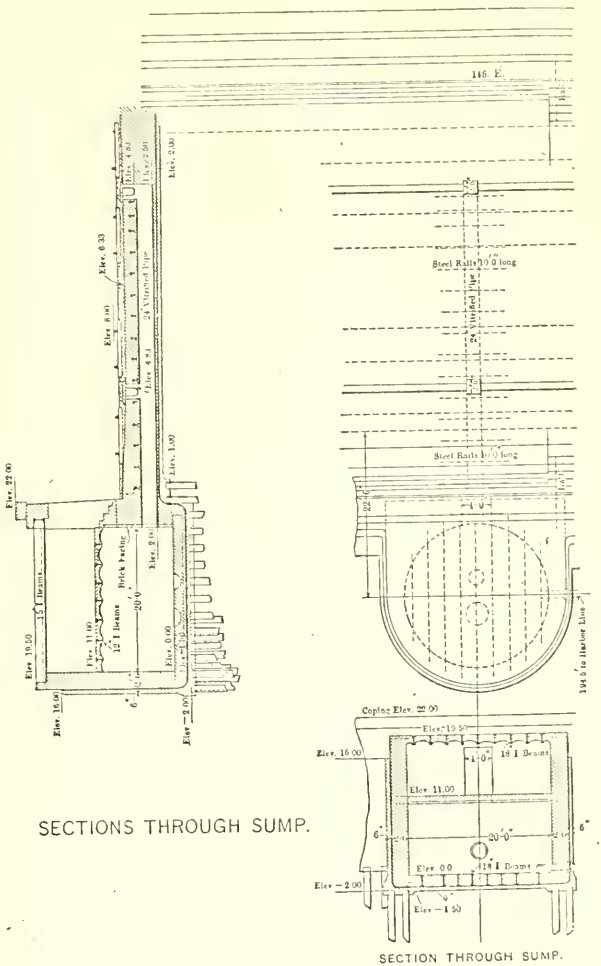
These pumps discharge through check valves to a pipe connection with the city storm sewer, which crosses the premises and empties into Fort Point Channel.

Thus far, the pumps have seen very little service, and it is to be hoped that it will not be increased.

At extreme low tide the small accumulation of water during the high-tide period finds its way through the check valves, which act as automatic flood gates to empty the sump well without the pumps. If the check valves fail to work on the rising of the tide, the alarm rings in the power house, and the emergency stop valve in the discharge pipe is immediately closed before any damage can be done.

Coal Handling.

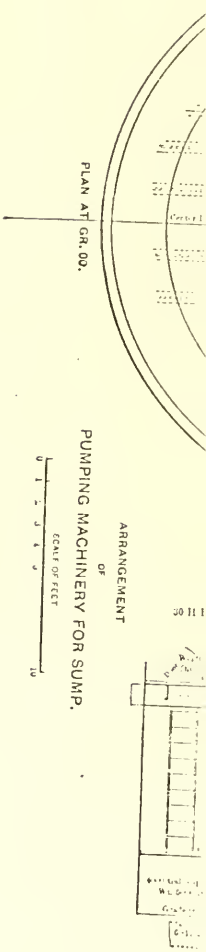
As the Terminal Company has no water front suitable for the discharge of coal from vessels, the coal is brought from one of the coal pockets belonging to one of the operating railroad companies, on cars which permit of unloading through hoppers in the floor. These are set over a coal vault, constructed in the rear of the boiler house, as shown on the cross-section plan, Fig. 12, and the coal is then dumped upon an intermediate floor, level with the hoppers of the mechanical stokers, this floor having storage capacity for several days' supply. From this floor the coal is pushed or shoveled into the mechanical stokers. Beneath this intermediate floor is further storage room for several days' supply, which supply is held in reserve against snow blockades in the winter, when it would be difficult to move the cars. From this lower floor it is necessary to lift the coal about 5 ft. to put



SECTIONS THROUGH SUMP.

SECTION THROUGH SUMP.

FIG. 17.



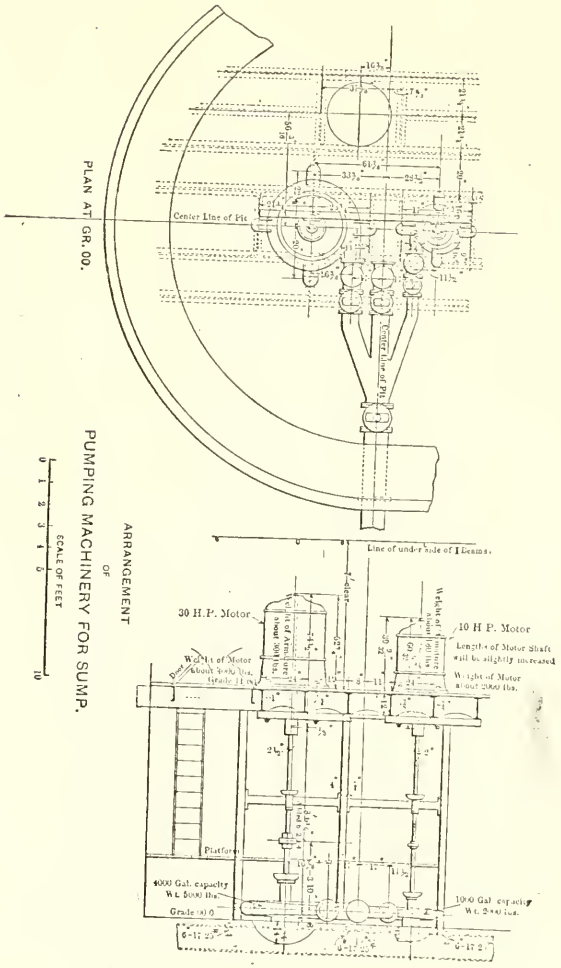

PLAN AT GR. 00.
Center Line of Pit
Center Line of Pit
Line of under side of I Beams.
30 H.P. Motor
10 H P. Motor
Length of Motor Shaft will be slightly increased
Weight of Motor about 2000 lbs.
Platform
4000 Gal. capacity
Wt. 5000 lbs.
Grade 00.0
1000 Gal. capacity
Wt. 2000 lbs.
SCALE OF FEET
0 1 2 3 4 5 10

FIG. 18.

ARRANGEMENT OF PUMPING MACHINERY FOR SUMP.

it into the stoker hoppers. Originally, it was not intended to have mechanical stokers, and to fire by hand from this lower level without this 5-ft. lift; but, after the stokers were installed, the intermediate floor was arranged, and the handling simplified, as well as the storage room increased.

Storage capacity for several thousand tons was considered, but on account of the relatively small consumption, varying with the seasons, from about 8 tons to 35 tons per day, the difficulty of placing the storage close to the boilers, the necessity of considerable coal-handling machinery, if not so placed, the necessity of using cars in any event, and the ability to take advantage of low prices, due to bulk deliveries, by purchasing in connection with one of the operating railroad companies, such storage facilities were not constructed.

At present, the ashes are wheeled from the furnaces to an area just outside of the boiler room, where they are taken away daily by private parties without cost to the Terminal Company. They are eventually disposed of either for cinder-concrete material, or to go to the South Boston flats for wharf filling, where a price is paid sufficient to cover the cost of handling.

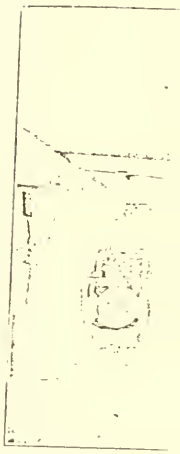


Fig. 1 Appa

Cost of Power Plant.

The cost of the entire power plant, including all piping, wiring, electric lighting of every sort, fans, heaters, radiators, air fixtures, frost jackets, ventilating system, steam connections, refrigeration, hot-water pipes, lifts and elevators in the head house, subway, express and gas buildings and train shed, as well as pumping plant in the sump well, has been, not including the interlocking, upwards of $400 000. The various parts are so inter-related to each other that no attempt will be made in this paper to give unit costs for elevators, lifts, lights, etc.

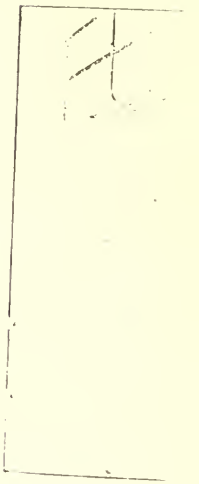


Fig. 2

Pintsch Gas.

A plant for the manufacture of Pintsch gas for use in cars has been established on the terminal grounds, capable of making 120 000 cu. ft. of gas daily.

A building, 110 ft. long and 40 ft. wide, two stories high, of similar type to the power house, has been constructed, on pile foundations; and in this building there have been installed 40 retorts and the accompanying furnaces, 3 engines and compressors for compressing the

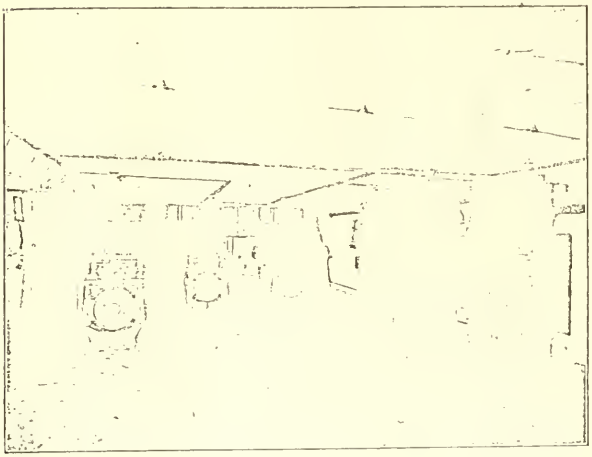


FIG. 1.—APPARATUS FOR THREE MAIN ELEVATORS AND CONTROLS.

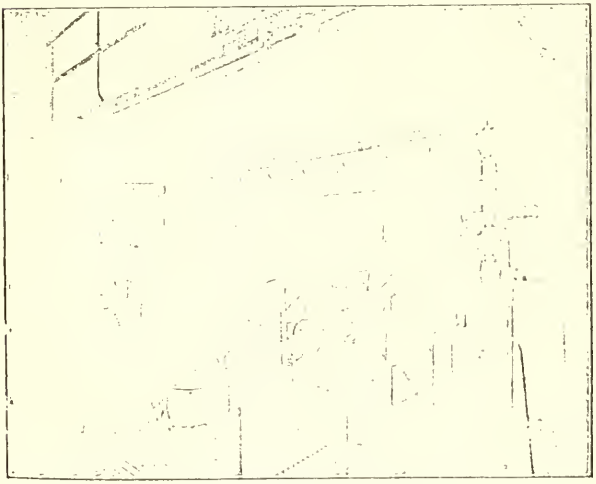


FIG. 2.—CIRCULATING PUMPS, CENTRAL HEATING PLANT.

gas, purifiers, meter, feed tanks, drip and tar pumps, and all other necessary appliances. The building is lighted by electricity. Outside of the building are installed 2 oil-storage tanks, a tar tank, 10 store holders and a gas holder 30 ft. in diameter and 15 ft. deep. A main pipe leads from this plant, connecting with distribution pipes to 120 outlets in the train shed and about 20 more outlets in the express yard, where gas can be put into the car tanks through hose connections. The cost of this entire gas plant, including the building, is about $80 000.

Material Used.

The material used in the work approximates: 43 000 spruce piles, 15 100 000 common brick, 487 000 medium brick, 846 000 enameled brick, 74 000 cu. yds. concrete, 32 000 cu. yds. stone masonry, 30 000 000 lbs., or 15 000 tons steel, equal to about 1 200 car loads; 200 000 cu. ft. of cut stone for building, or 500 car loads; 75 000 bbls. Portland cement, 20 000 bbls. Rosendale cement, 8 000 bbls. coal-tar pitch, 6 500 bbls. prepared asphalt, 850 000 lbs. tarred paper, 450 000 lbs. sheet copper for roof trimmings; 5 000 000 ft., B. M., yellow pine timber, for various uses; 16 000 lbs. solder, 10 acres gravel roofing, 150 000 sq. ft. wire-glass and 40 000 lbs., or 20 tons, of putty to set the same.

Costs of Yard Buildings, Per Cubic Foot.

The power house, including foundations	$0.121
The gas building, including foundations	0.135
The express buildings, including foundations	0.131

The total cost of these buildings aggregates $310 000.

These buildings are of brick, two stories high, with good basements, founded on piles, with iron floor-beams, iron roof-trusses, wooden floors and roof boards, roofs covered with tar and gravel, plumbed, heated and lighted, and the express buildings contain offices for 250 persons; also 5 truck lifts. The above costs do not include any foundations for machinery located within these buildings.

Cost of Head House.

The approximate cost of the head house, including foundations, heating, lighting and elevators, is $1 565 000, or $0.214 per cubic foot. In calculating the cubic feet, outside dimensions and height from floor of basement to top of roof are used.

Cost of Train Shed.

Area, 343 140 sq. ft. Weight of steel, 23 lbs. pe. square foot. Total cost, including foundations, steel and covering, $382 180. Cost per square foot, horizontal area, $1.11. If the area and cost of the midway and connecting roofs is added to the train shed, the cost is $1.05 per square foot, horizontal area.

Organization for Construction.

The Terminal Company is managed by a board of trustees, one for each of the five constituent railroad companies.

The members of the board were as follows:

Charles P. Clark, Chairman, representing The N. Y., N. H. & H. R. R. Co.
Samuel Hoar, Vice-Chairman, representing The B. & A. R. R. Co.
Charles L. Lovering, representing O. C. R. R. Co.
Royal C. Taft, representing B. & P. R. R. Corporation.
Francis L. Higginson, and later, John M. Hall, } representing The N. E. R. R. Co.

The construction work was carried out under the direction of the architects, Messrs. Shepley, Rutan and Coolidge, and the Resident Engineer, the former planning and supervising the brick and stone head house and office-building construction, and the latter the foundations, train shed, midway, tracks, subways, express buildings, power house, sea wall, etc., and supervising the construction of the power plant and interlocking, each of the above parties reporting directly to the Board of Trustees.

The Chief Engineers of the operating railroads and the Manager of the Terminal Company exercised general criticism, and were consulted in regard to the requirements. All the large contracts for construction were executed on behalf of the Terminal Company by a member of the Board of Trustees. Other contracts were executed, under authority of the Trustees, by the Architects or Resident Engineer.

The general plans for the steel construction in the train shed and bridge floors, prepared by the Resident Engineer, were developed by J. R. Worcester, M. Am. Soc. C. E., of Boston. The shop cards were drawn at the office of the contractors, the Pennsylvania Steel Company, J. V. W. Reynders, M. Am. Soc. C. E., Superintendent, and were examined, checked and approved by the engineering department of the Terminal Company.

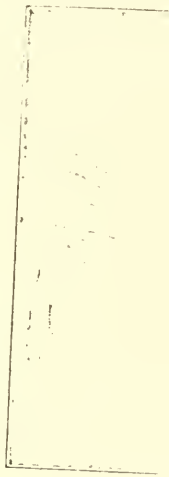


Fig. 2.—Train S.

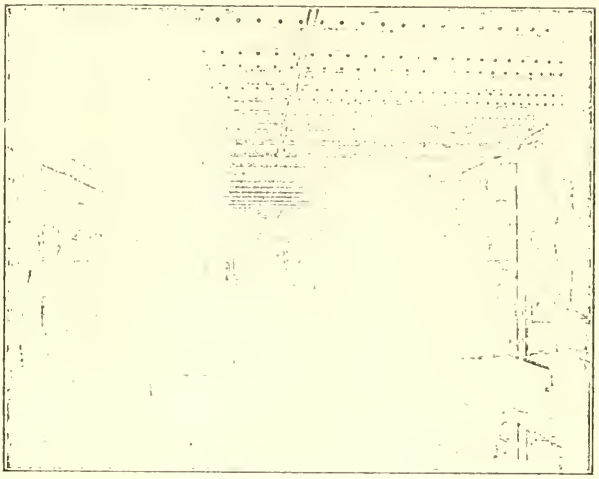


FIG. 1.—EXPRESS SUBWAY.

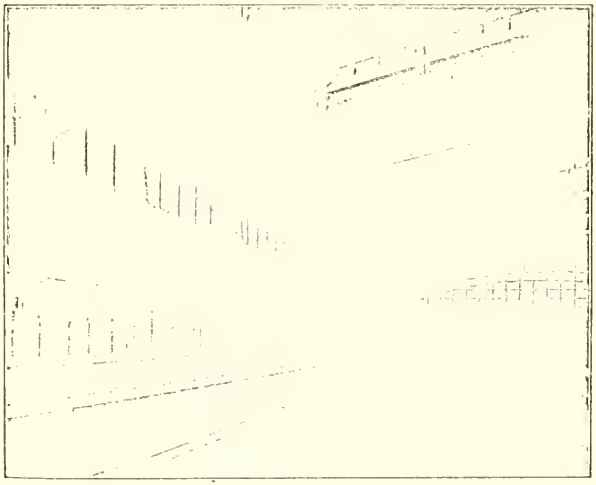


FIG. 2.—TRAIN SHED, SHOWING LEADERS ENCASED IN FROST-PROOF JACKETS.

The interlocking plans and details were made by the Union Switch and Signal Company, of Swissvale, Pa. The power plant, including lighting, heating, ventilating, elevators, lifts and ice-making machinery, was designed by or under the direction of Westinghouse, Church, Kerr & Co., of New York; Henry J. Conant, their Boston representative, the Sprague Elevator Company, and Professor S. Homer Woodbridge, heating and ventilating engineer, contributing to this end. The plans for the Pintsch gas apparatus were designed by the Pintsch Compressing Company, of New York.

The engineering department of the Terminal Company, assisting the Resident Engineer, embraced A. B. Corthell, M. Am. Soc. C. E., First Assistant Engineer; W. F. Goodrich, M. Am. Soc. C. E., Assistant Engineer, in charge in the field; J. H. O'Brien, architectural draughtsman, as well as other draughtsmen, instrument men, inspectors and helpers, all of whom, as well as the head men for the various contractors, faithfully carried out all the work entrusted to them.

Organization for Operation.

The organization for operating the station is at present substantially as follows:

A Manager, to whom all reports are made, and who himself reports to the Trustees.

For the Transportation Department, a Station Master and an Assistant Station Master for day and night service, with the necessary force of guides, gatemen, porters and cleaners.

A Ticket Agent, with necessary force, Yard Master and Assistant Yard Master, Baggage Agent and Parcel Agent, each with necessary force.

For the Maintenance Department, the following heads, reporting upon all matters pertaining to construction, repairs and operation, excepting operation of the interlocking plant, through the Resident Engineer to the Manager: Superintendent of Power Plant, including all matters pertaining to mechanical and electrical equipment, lighting, heating, ventilation, elevators, ice and gas machinery, with the necessary force; Supervisor of Buildings, with necessary force; Track Master, with necessary force. There is also a Supervisor in charge of all apparatus and employees supplying steam, compressed air and Pintsch gas to cars, he reporting to the Manager.

The Treasurer of the company, who at present is also Acting

Auditor, Pay Master and Purchasing Agent, reports directly to the Board of Trustees, the same as during construction.

Train Service.

The natural position of the four roads entering the station will be maintained in the train shed, as far as possible. There being eight main tracks through the throat, two can be devoted, one in and one out, for each road; and only the necessary crossing of trains of one road over the tracks used by another road, done, as is necessary, to reach baggage rooms, express yards, or other special service. As two-thirds of the 737 trains using the station are suburban trains, without baggage or express matter in quantity, this very much reduces interference upon the grand crossing. Those trains carrying large quantities of baggage and express matter must, of course, get as near the inward or outward baggage rooms as possible. It has been found thus far, in operation, that the baggage lifts expedite rather than hinder the free movement of baggage, as the free cross-run of the trucks beneath the tracks, compared with dodging trains on the surface, more than compensates for the time required to use the lift.

Fencing.

The property has been surrounded as far as possible on its boundary limits with a fence 8 ft. high; a part of this, adjacent to the streets, being a tight board fence, and upon division lines a picket fence, with proper gates for entrance and exit to the express and mail yards. The subway and sea walls are lined with a heavy two-pipe rail fence with cast-iron posts.

Minor Conveniences.

It is impracticable in this paper to describe the large number of minor conveniences which have been arranged for this station. The mention of a few of them will suggest their importance and help to complete the record.

A private telephone exchange for the terminal only.

Separate ticket-selling booths for each man.

A liberal number of weighing scales in baggage rooms and express buildings.

Ample bicycle racks, check racks, etc.

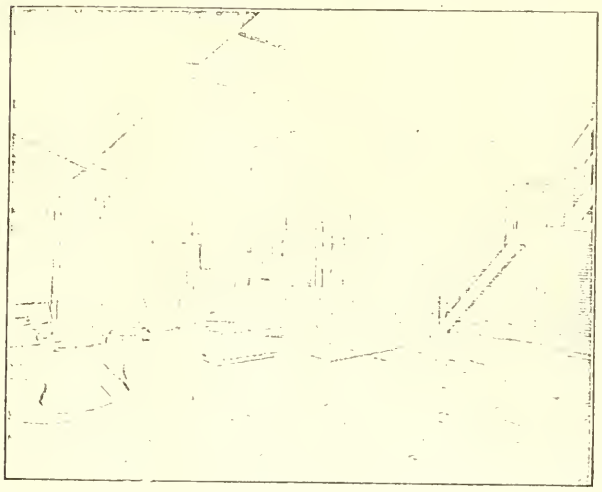


FIG. 1.—VIEW OF ICE TANK.

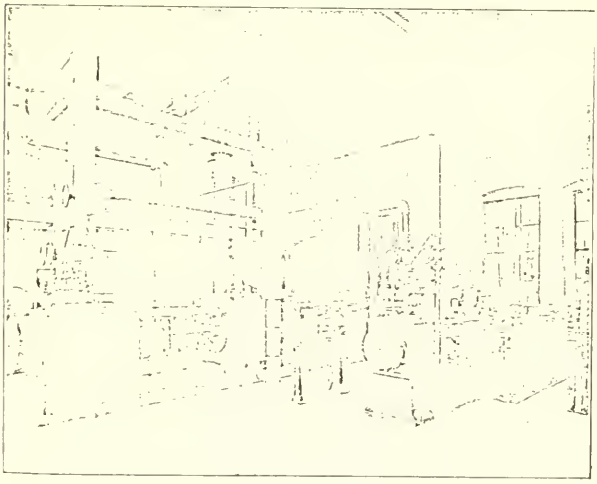


FIG. 2.—VIEW OF AMMONIA COMPRESSORS, ICE PLANT, ETC.

Checking system to care for trainmen's coats, hats, etc., instead of the usual lockers.

Kitchen and restaurant furnishings.

Booths for weighers at scales in express buildings.

Apartments for car inspectors.

Train mail-chute and sorting room.

Speaking tubes.

Case for sale of emergency articles, rubbers, umbrellas, etc., in women's room.

Shoe-cleaning and polishing chair in women's room.

Room for police squad at the station.

Dressing room for porters and gatemen.

Conveniences for handling newspapers.

Carpenter and paint shop for repair men.

Blacksmith shop for interlocking and track work.

Shop for small repairs to machinery and piping.

Stock rooms, oil house, lamp room, trackmen's tool room, yardmaster's office, trackmaster's headquarters and interlocking supervisor's room, storage yard for spare track material, etc., etc., etc.

Conclusion.

In conclusion, it gives no little satisfaction to the engineering department to say that throughout the entire construction there has been absolutely no friction between any of the parties who have contributed to the grand result, either as railroad officers, managers, architects, engineers, contractors and their representatives, or city and state heads of departments and officers, and that uniform courtesy has prevailed among all.

While it is not always the duty of the engineer to discuss the wisdom or necessity of certain lines of policy, and while such discussion is more or less unprofitable, it may, nevertheless, in this instance, prove valuable to answer in advance the questions sure to be raised as to whether such a large terminal, with its accompanying expenditures, is a proper investment for a railroad company to make.

When railroad stations have been utterly outgrown, as was the case in Boston, and the traffic cannot be properly handled, there is "no alternative" for the railroad management but reconstruction. The question whether each of the existing stations shall be enlarged, per-

haps under great difficulties, or whether a combination shall be effected, as in Boston, for the mutual convenience of the transportation companies and the public, is usually well weighed and decided by those most competent to decide. Having decided to build a new station, no management can be criticised for making it an up-to-date and even ahead-of-date structure.

Of the great expenditure necessary for the new terminal station in question, probably nearly two-thirds of its entire cost for land and buildings reverts directly or indirectly to the railroads interested, in lands released at old stations for other purposes or for entire disposal. With bonds selling at a premium on a $3\frac{1}{2}\%$ basis, much more can be accomplished, with the same interest charge, than was possible a few years ago, with interest at 6 per cent.

As far as can now be determined, the cost of operating the new and much more commodious station will be about the same as the sum of operating the old stations.

A railroad station is a minor appurtenance to the road itself, and it is impossible to always incur expense for renewals, on the basis of an investment upon which a new direct return will be forthcoming.

It may be compared, roughly, to a new storehouse for a cotton mill. It is a necessary convenience for the handling of the business, but the mill (or the railroad) is the real earning factor.

The question has been asked: "How much money did the City of Boston contribute toward the construction of the station?" In reply, it may be said that not one dollar was contributed, directly or indirectly, by the city for land or structures upon the terminal location. The city, through its own departments, was authorized by the Legislature, to expend a sum of money for streets and bridge construction, outside of the terminal property, not to exceed $2 000 000.

At different times a great many suggestions have been contributed to the terminal management, regarding construction of train shed, arrangement of tracks, handling of baggage, operation of station, etc., etc. Many of these were ingenious, some utterly useless. As a rule, nothing is accomplished if we wait until perfection is reached, and it is undoubtedly better to go ahead imperfectly than not at all.

The station is now being operated without delay to trains or people, and the results aimed at have been reasonably attained. Later on, when the subway station is put into service, there should be still greater satisfaction in the general operation.

INDEX OF SUBDIVISIONS.

	PAGE
Air Brake Testing	159
Ballast	125
Borings	109
Bumping Posts	125
Car Heating	159
Cement	118
Coal Handling	161
Coffer Dam	113
Concrete	116
Construction Drawings	119
Electric Lighting	151
Elevators and Lifts	155
Encumbrances	110
Express Buildings, Team and Car Yards	146
Fencing	168
Fire Protection	160
Frogs and Switches	125
Frost Protection	160
General Plan	110
Head House	136
Head House, Cost of	165
Head House, Heating and Ventilating	156
Head House, Steam and Hot Water for	159
Heating and Lighting Express and Yard Buildings	147
Heating and Ventilating Head House	156
Ice Making and Refrigeration	158
Interlocking	141
Land Plans	108
Material Used	165
Midway Fence	128
Midway Floor	127
Minor Conveniences	168
Organization for Construction	166
Organization for Operation	167
Pile Test	109
Piling	116
Pipe Subway	147
Pintsch Gas	164
Platforms	124
Plumbing	140
Power House Equipment	150
Power Plant Buildings and Pipe Subway	147
Power Plant, Cost of	164
Pumping Plant	161
Rail	125
Signal Lights	146
Steel Flooring and Asphaltic Protection	123
Stone	119
Ties	126
Track Arrangement	123
Track Grades	146
Train Indicators	128
Train Service	168
Train Shed, Cost of	166
Train-Shed Covering	135
Train-Shed Steel	128
Waterproofing	114
Water Supply	140
Yard Buildings, Cost of	165
Yard Buildings, Heating and Lighting	147

DISCUSSION.

Mr. Conrow. HERMAN CONROW, Jun. Am. Soc. C. E. (by letter).—The method used by Mr. Francis in water-proofing the masonry throws new light on a subject upon which comparatively little has been written.

In the summer of 1896 the writer had charge of the construction of a water-proof subway, beneath the four tracks of a railroad in Massachusetts. The subway was about 100 ft. long and 8 ft. in clear width, with the floor about 5 ft. below the level of the water in a nearby creek. It was necessary, therefore, to build a masonry structure which would be impervious to water under pressure. The design of the subway called for a foundation of concrete, brick side and end-walls, and a brick-arch roof with concrete backing. The water-proofing materials were refined bitumen asphalt of the best quality and heavy tarred paper. Inside, the finished subway was planned to have a mosaic floor and sides and arched ceiling of glazed bricks; but these embellishments have nothing to do with the water-proofing, and were added merely as a veneer to the main walls of the structure. The subway was built in a soil of fine sand so full of water that it was not far removed from a quicksand.

In order to simplify the description, the methods used in water-proofing the floor, side-walls and roof are separated.

1. The floor was water-proofed as follows: A foundation course of concrete, 6 ins. thick, was laid upon the sand, and the top of this was roughly leveled and smoothed by filling the depressions with mortar. After this mortar had set, heavy tarred paper was laid to break joints, and over the paper was poured a layer of molten asphalt. (The thickness of this pouring will depend upon the temperature of the asphalt. Very hot asphalt will run out to a thickness of less than $\frac{1}{4}$ in.; but it can be used so that the pourings will be nearly $\frac{1}{2}$ in. thick. The thin pourings, however, give the best results.) On this asphalt, after it had cooled, another layer of tarred paper was placed, which was followed by another coating of asphalt. This process was continued until a water-proof covering about 1 in. thick was formed. This was composed of three layers of paper and three pourings of asphalt. This floor covering could have been made entirely of asphalt, but the tarred paper greatly increased its strength.

Upon this water-proof floor 6 ins. of concrete were next laid, except where a space was left for the asphalt in the vertical walls to join directly to the asphalt floor. The purpose of this concrete was to keep the asphalt permanently cool and also to withstand the water pressure from beneath. Steel rails, 2 ft. apart, were placed in the concrete, and the ends of the rails were bedded under the inside walls.

thus giving strength to the concrete, in addition to its weight, to resist the upward pressure, otherwise a heavier layer of concrete would have been necessary. Mr. Conrow.

2. To water-proof the side-walls of the subway the general scheme was to build a core-wall of asphalt, 2 ins. thick, between two brick walls. The greatest care was necessary, in making the junction at the bottom, where the asphalt core-wall met the asphalt floor, to secure a water-tight joint. The inside wall surrounding the core was first built

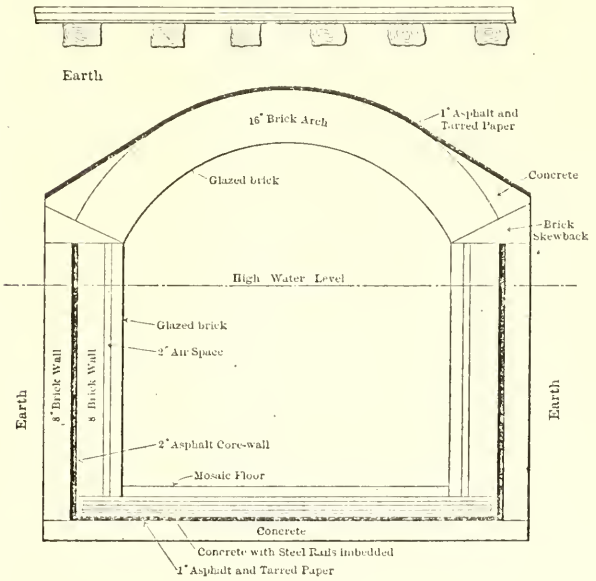


FIG. 19.

to a height of 6 ins. and the outside wall to a height of 1 ft., thus forming a narrow groove 12 ins. deep, into which molten asphalt was poured. In order to reduce the amount of asphalt, broken pieces of clean and dry brick were laid in the groove, which was then grouted full with very hot asphalt. The core-wall having thus been raised level with the brick walls about it, the brick walls were built up 12 ins. higher, and the process of asphalting repeated. In this manner the

Mr. Conrow. sides and ends of the subway were built to the desired height. When this had been done the walls and bottom formed a water-tight masonry box.

When starting the core-wall at the bottom, the asphalt was poured very slowly, for there was danger that the hot asphalt would melt that under the concrete and cause it to crack; but after the core-wall had reached a height of 1 or 2 ft., all anxiety on that score was dismissed.

To make a tight junction between one pouring of asphalt and another, the surface of the cold asphalt must be perfectly clean and dry. A film, either of dust or moisture, will prevent a water-tight junction. Sometimes, when the brick walls had been freshly built up above the core-wall, particles of mortar and drops of water collected upon the surface of the cold asphalt in the groove, and, in spite of brushing and wiping, it could not be cleaned and dried perfectly. In such cases a small quantity of kerosene was sprinkled on the surface of the asphalt in the groove and then lighted. The heat dried out the moisture and melted the surface of the asphalt, giving a perfectly new surface and making sure the unity of the work.

This use of kerosene the writer has found very valuable. Old surfaces of asphalt which had become full indentations and which were covered with sand which had become ground in, were rendered bright and clean by burning kerosene on the surface; the foreign particles disappeared by sinking deeper into the asphalt, leaving the surface in good condition to unite with the next pouring.

3. The water-proofing of the arch covering was very simple. After the masonry had been smoothed over with cement and it had set, asphalt was poured evenly over the surface, and, after cooling, a layer of tarred paper was laid, beginning at the sides and parallel with the barrel of the arch, working upward toward the crown, each course lapping over the previous one as in a shingle roof. Four layers of asphalt and three of paper were used.

The water-proofing of the subway by these methods was entirely successful, and upon the completion of the work the pumps were stopped and the water rose to a height of 4 ft. around the walls of the subway, which remained perfectly dry inside. Numerous heavy rains caused no leakage in the arched roof.

This method of water-proofing the side walls was not that originally tried upon this work. At first the attempt was made to water-proof a brick wall by means of paper and asphalt. After the wall had become dry it was coated with asphalt, and then paper was put on with lap joints. Another coat of asphalt followed, then more paper, and so on. A 4-in. brick wall was built adjacent to the paper to hold it and the asphalt in place. The results were not successful, and perfect water-proofing was not secured in this way. The writer is of the opinion

that tarred paper has little value as a water-proofing material for ver- Mr. Conrow.
tical walls which are to stand water under pressure, because of the impossibility of keeping the paper in its proper place. He also believes that if it is desired to build masonry absolutely water-tight the best way to do it is by using an asphalt core-wall where the asphalt may be poured into a groove and allowed to run into every crevice which will admit water.

Both the asphalt and the tarred paper should be of the best quality. Cheap asphalt and the tar compound are not permanent substances, but will rot and become like powder under the action of water and air, thereby loosing all water-proofing qualities; and the poorer kinds of tarred paper are easily torn and are of little value. It will be found very difficult to handle the asphalt in hot weather since it becomes soft in ordinary summer temperatures. Cold asphalt is a durable and tough substance, capable of bearing considerable pressure, but if unprotected from the sun's rays, it becomes an unreliable material. If it is desired to use a large quantity of asphalt, the inconvenience of melting it quickly may become very great, especially if the asphalting outfit consists of but one or two kettles. One kettle will melt a large amount, however, if it is kept constantly full, since the molten asphalt in the kettle will quickly melt large blocks of the cold asphalt.

The accompanying section, Fig. 19, will aid in the illustration of the methods described.

J. R. Worcester, M. Am. Soc. C. E. (by letter).—The subject em- Mr. Worcester.
braced by the paper is so comprehensive that the author has, of necessity, hastened over many features of the problem, a more extended account of which might have been interesting to the members of the Society. In the hope of shedding a little light on some of these points, the writer wishes to discuss briefly the portion of the paper which refers particularly to the train shed.

Cantilever Principle.—To make more clear the reasons for adopting the cantilever style of trussing, it should be stated that before the method of supporting the roof was determined, the cross-section, so far as the roof line was concerned, was agreed upon almost exactly as it was finally built. This line was arranged so as to give a large vertical space for windows below the eaves and above the connecting roof, to enclose the whole width of the shed under a single roof and to avoid raising any portion so high as to overtop the head house. It was also determined that there should be two lines of intermediate columns placed substantially in the positions finally adopted.

With these conditions prescribed and with the manifest advantages of raising the bottom chord as much as possible, the cantilever principle naturally suggested itself as desirable. To ascertain whether it would result in any great economy, however, an estimate of the cost of trusses with the same outline, but broken over the interior columns,

Mr. Worcester. was made. It was found that the weight of trusses constructed on these lines would be about 10.7 lbs. per horizontal square foot, instead of 8.25 lbs., which was the weight of the cantilevers.

Whether the supported trusses could have been made as light as the cantilevers, had the shape been immaterial, was not determined; but it is doubtful, as the conditions, particularly the fact that only a small portion of the load was variable, were altogether favorable for cantilever construction.

Expansion.—The author has referred to the fact that only one expansion joint was provided in the trusses, and that in the central span; but in speaking of the intermediate columns as not anchored, he might be understood to mean that it was expected that motion might occur at the feet of these columns from changes of temperature. This was not the case, as it was recognized that the friction from the load on these intermediate columns would be so great as to render motion impossible, even if desirable. The side columns were made very stiff, and were calculated on the assumption that all the wind force would be transferred through them to the ground. Assuming, then, that the trusses were fixed at the outer end, it was expected that the intermediate columns must bend slightly as the length of the end spans varied with the temperature. Allowing for a motion of 1 in. per hundred feet, as the extreme effect of temperature, it was found that the strain caused by this motion in the intermediate column would not add above 25% to the compression caused by the total vertical load, and the combined strain would be only about 12 500 lbs. per square inch.

As a matter of fact, it seems that the allowance of 1 in. per hundred feet was excessive, for it was found that the total change at the expansion joint between a very hot summer day, when, before the covering was all applied, parts of the trusses were exposed to the direct sun, and an unusually cold winter day, before the shed was occupied and partly warmed as it will be by occupation, that is, under a range of 94° Fahr., the maximum contraction at the central expansion joint amounted to only $1\frac{1}{8}$ ins. This is partly explained by the fact that the side posts, instead of being absolutely rigid, as assumed, allow a motion at the top of apparently about 1 in., making a total contraction of about $3\frac{1}{8}$ ins., or $\frac{5}{16}$ in. per hundred feet.

In this connection, the writer can hardly agree with the author's conclusion with regard to the Midway Floor, that "the expansion of each piece of steel is apparently taken up in the riveted joints." It seems more probable that, as the extreme variation in temperature of this portion of the building probably does not exceed 40°, the elasticity of the material is called upon to compensate for any motion which might occur if the material were free to come and go.

General Design.—There are two points in the general design of the

train shed which are not very clearly set forth in the paper or illustrations, and about which a word may not be out of place. Mr. Worcester.

The trusses at the ends of the building, viz., *A*, *B*, *C*, *K*, and *L* are made the full depth of the end, with diagonals each extending over two of the panels indicated by the vertical lines on the cut.

The verticals of these trusses act as beams to carry the wind pressure to the horizontal trusses which are situated in the plane of the top and bottom chords.

The reason for making the main monitor trusses with a 60-ft. span, disregarding the supports which might have been carried to the top of main trusses, was that these trusses are spaced more closely together than the main trusses, those intermediate between the main trusses being carried by the purlins on either side.

Pin and Rivet Connections.—Pin connections were adopted for the main trusses, and for much of the rod bracing, largely as a matter of convenience of erection and to improve the general appearance. There was, however, one very important detail where a riveted joint was used, namely, at the intersection of the bottom chord of the cantilever trusses with the intermediate columns. Here a pin would have been of such large diameter and the necessary restriction in metal of the post so great, to say nothing of the difficulty of having the chords on the two sides of different widths, that a riveted joint was much more satisfactory, and it was adopted without hesitation.

Length of Struts.—One feature of the design which was of considerable importance in the way of economy, but which was somewhat contrary to modern practice, was the ratio of length to diameter allowed in struts in riveted work. If rules such as that "the length shall not exceed 100 times the least radius of gyration" had been adopted, it is safe to say that the purlins and a large amount of the bracing members would have had to be made up of different shapes altogether from those used. The limit adopted was for the length not to exceed 50 times the least diameter. In the writer's opinion, the least diameter in such a limit is a more proper guide than the radius of gyration, as the stiffness of the member, which is the element most to be considered, more closely corresponds with the former. Whether the ratio of 50 is too great is open to debate, but where the members are straightened carefully after riveting, and again looked after when erected, and where, as in a roof, they are not liable to transverse forces of any kind, it seems a wise economy to use a liberal ratio.

Jack Rafters.—It was considered very desirable, in covering the roof, to arrange if possible a truly curved surface which should not show breaks over the purlins, as there are many points of view outside the building from which the line of sight would quickly detect any unevenness. It was therefore with some trepidation that the writer specified for the jack rafters 8-in I-beams, the span being about

Mr. Worcester. 20 ft. This was finally done, but the beams were given a camber greater than that required by the curve of the roof, by an amount (1 in.) which was approximately the theoretical deflection which the beam would have from the dead weight of the covering. The result of this was very satisfactory, the lines of the roof taking a very even curve.

In this connection, it is interesting to note that at the bottom of the slope the pitch is not less than 3 ins. per foot, the steepest which the writer has known of for a similar composition roofing. So far no evil effect has been observed.

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